MECHANICAL ENGINEERING

A PRACTICAL TREATISE

ON

MECHANICAL ENGINEERING

COMPRISING

METALLURGY, MOULDING, CASTING, FORGING, TOOLS, WORKSHOP MACHINERY, MECHANICAL MANIPULATION, MANUFACTURE OF THE STEAM-ENGINE, ETC.

By FRANCIS CAMPIN, C.E.

PAST PRESIDENT OF THE CIVIL AND MECHANICAL ENGINEERS' SOCIETY; AUTHOR OF "IRON BRIDGES, GIRDERS, ROOFS, ETC.;" "MATERIALS AND CONSTRUCTION," ETC., ETC., ETC.

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PREFACE.

The present work is, substantially, an abridgment of my larger treatise on the same subject, published some years since; but I have found it necessary to entirely re-write the text, the improvements in mechanical manipulation which have been introduced during that period having rendered obsolete many of the processes described in the earlier treatise.

A quantity of descriptive matter has been eliminated and replaced by accounts of vacuum brakes and other modern appliances.

I have endeavoured throughout to give not only a description of the various mechanical elements, but also to explain the modes of practically constructing them, in order, as far as it is possible on paper, to instruct the student in workshop operations.

FRANCIS CAMPIN.

Leeds, 1881.

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MECHANICAL ENGINEERING.

INTRODUCTION.

Iron, and the other metals used for mechanical purposes, not being found pure in a natural state, must be freed from some or all of the substances with which they are associated in their ores, to render them fit for the purposes of commerce. For the removal of these foreign ingredients various chemical and mechanical processes are employed. In the first place it is necessary to remove the argillaceous matrix with which many ores are contaminated. Some are then roasted to expel moisture, &c., and subsequently smelted in order to obtain the products in the metallic form.

The process of smelting is a chemical operation, and consists principally, in the case of iron, in depriving the metallic oxide of its oxygen, which is effected by carbon at a high temperature, which by its superior affinity for oxygen reduces the ferruginous material to the metallic state. In the case, however, of ores consisting of metallic sulphides, a different process is requisite, as will be shown subsequently.

After smelting the iron appears as cast iron, and from this, wrought iron is obtained by further purification. Cast iron contains many impurities, consisting principally of silicon, manganese, carbon, sulphur, phosphorus, alu-

minum, and sometimes traces of arsenic, copper, &c. Most of these elements may be removed by oxidation in the form of slag, and in the removal of these impurities consists the conversion from cast to WROUGHT IRON: the process may be conducted by exposing a large surface of the heated metal to the oxidizing influence of atmospheric air.

From wrought iron STEEL is formed, by combining with the metal certain proportions of carbon, and in the opinion of some chemists, nitrogen is also associated. It cannot be expected that a number of foreign elements will remain in combination with a given metal without producing marked effects on its physical character; and thus we find that cast is widely different in its nature from wrought iron. Cast iron is granular, brittle, rigid, elastic, and offers but little resistance to tensile force, although it well withstands crushing effort; on the other hand wrought iron is, *or ought to be*, fibrous, tough, flexible, and offering great resistance to tensile force, but not so much to compression. These are the general characteristics of the two materials, but various specimens will exhibit the special qualities in very different degrees: thus we may sometimes see samples of bar-iron nearly as brittle as cast iron, while the latter can be made to possess a very superior degree of toughness, as has been produced in gun-metal.

Combined with iron, phosphorus, sulphur, and silicon appear to be highly injurious, whereas titanium, nickel, and perhaps manganese, exert a contrary action.

Steel, besides possessing in a high degree the qualities of wrought iron when in a soft state, admits also of being raised to various degrees of hardness, but when at its hardest is exceedingly brittle. To harden steel it is raised to a red heat and plunged into cold water, being moved about so as to insure rapid cooling; but in this condition it is too brittle for ordinary use, hence it requires tempering; to

effect which it is gradually heated, becoming the softer the higher the temperature to which it is raised. The proper point of temper is determined by the colour of the film of oxide formed on the surface of the metal, which colour depends on the thickness of such film—thus springs are tempered to a blue tint, cutting tools, straw yellow, &c., &c.

It has been suggested that the physical difference between hard and soft steel is, that one holds the carbon as alloy, and the other in chemical combination; but however interesting such hypotheses may be, and doubtless are, the present work does not afford space for their discussions, hence I shall confine myself to the more strictly practical treatment of my subject.

Cast iron admits of being hardened by being cast in a mould so contrived that the edges or surfaces required to be hard are very rapidly cooled; this method is useful for such articles as ploughshares.

Cast steel is apt to be very porous or spongy if cast without the use of any special precautions, but by casting under pressure its condition can be greatly improved, so low a pressure as 200 or 300 lbs. per square inch producing marked effects. It is curious to observe that the gases which occupied the cavities in the ingot, are probably absorbed as it were in the molecular interstices of the mass.

I must now offer a few remarks upon the other materials of which I shall subsequently treat. Copper as found in commerce is prepared in a state of comparative purity; but the processes involved in its reduction are exceedingly complicated, several operations in reverberatory furnaces being necessary to obtain the metallic product from the cupric sulphide. The metal is ductile, but requires, when being worked, frequent annealing; it may be wrought under the hammer cold, but works better when slightly heated.

It has been found that the addition of a small quantity

of phosphorus materially increases the strength of copper; for although this element is so detrimental to iron, yet when it is combined with copper in the proportion of from two to four per cent., it imparts to that metal such hardness and tenacity, that its tensile resistance becomes about four-fifths that of average wrought iron.

In mixing the phosphorus with the copper, it is necessary first to coat it with copper, which is done by immersing it in a solution of the sulphate of that metal. It is thus rendered secure from oxidation during the very short period required for its immersion in the molten metal with which it is to be combined. Copper when combined with about four per cent. of silicon, possesses the hardness of steel and the tenacity of wrought iron, and if this alloy could be manufactured on a large scale conveniently, would doubtless be found applicable to a great variety of purposes.

One of the most important alloys of copper is brass, though gun-metal is probably almost as extensive in its applications. The strength, however, of brass is not equal to that of the copper and phosphorus alloy.

The metals tin, lead, and zinc, will also require consideration in the ensuing pages, but it is not necessary here to comment on them further.

After the metals are obtained from their ores, their treatment by the mechanical engineer branches into two divisions: the casting into required forms, by pouring the liquid metal into suitably formed moulds, and the forging and pressing into shape of heated wrought metal; after this the two materials again find themselves in company under the hands of the fitters, turners, and machine men.

It is my object to show, as far as may be done on paper, how the various processes of manufacture are conducted, and to make clear the practice of mechanical manipulation in its various ramifications, and also to explain the rational principles upon which machinery, but especially steam

machinery, is designed. In pursuance of this intention, formulæ must necessarily be introduced, but I shall in all cases restrict them to such simple expressions as may be familiar to those who have only the most elementary acquaintance with mathematical science, my object being particularly to furnish a text-book for the "practical" student and intelligent artisan, to whom every facility should be afforded for systematizing and extending his theoretical knowledge of his trade.

In like manner, in order to make the work complete and rational, it will be necessary to consider the physical laws upon which depends the action of our steam and other thermo-motive engines, and in so doing, care will be taken to avoid the introduction of unnecessary technicalities, and in all cases where scientific terms are unavoidable, to clearly explain their meanings in the ordinary language of the workshop.

Having thus briefly indicated the various matters to the consideration of which the following chapters are devoted, I shall pass on to their detailed treatment.

CHAPTER I.

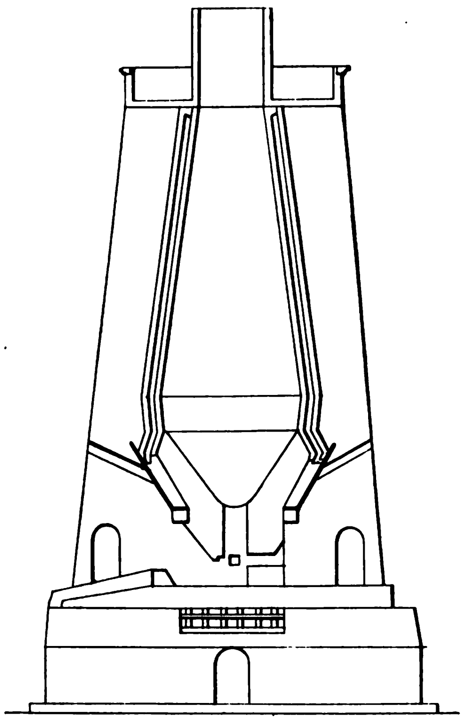
METALLURGY.

OF the minerals containing iron, those in which there is more than 20 per cent. of that metal are considered ores, others containing less are used as fluxes, the action of which will subsequently appear. The oolitic ores of Northamptonshire and Cleveland afford in many instances 33 per cent. of iron; but the iron-works of this country are principally supplied from the earthy carbonates of the coal measures. The coal-fields of North and South Wales, Staffordshire, Warwickshire, Shropshire, Yorkshire, and Scotland, contain abundant deposits of this ore.

I will now describe the ordinary process of smelting. For the reduction of iron, a blast furnace of the general form shown in Plate I. is used, but previous to smelting the ore, it is sometimes necessary to calcine it, which is effected in a kiln of the form shown in Fig. 1. The diameter of the kiln at the top may be 9 or 10 feet, the height 14 or 15 feet, with a bottom width of about 3 feet. At the bottom is an aperture for the withdrawal of calcined ore, and others for draught. Where mechanical appliances are used to lift the ore the kilns will be made of much larger dimensions, and fitted with spouts from which the calcined ore is run into trucks or barrows.

In firing a new kiln, a fire is lighted on its floor, and as soon as brisk combustion ensues other fuel is added, with *alternate strata of ore,* until the kiln is filled, care being *taken to work the kiln* so that these strata descend

PLATE I.



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uniformly, being exposed to a higher temperature at the upper part of the kiln, where active combustion is maintained; the temperature decreasing as the ore passes towards the aperture through which it is subsequently withdrawn.

In some districts the ore is calcined in heaps, but this process is very wasteful, and the results are unsatisfactory. Perfect calcination results in the expulsion of volatile con-

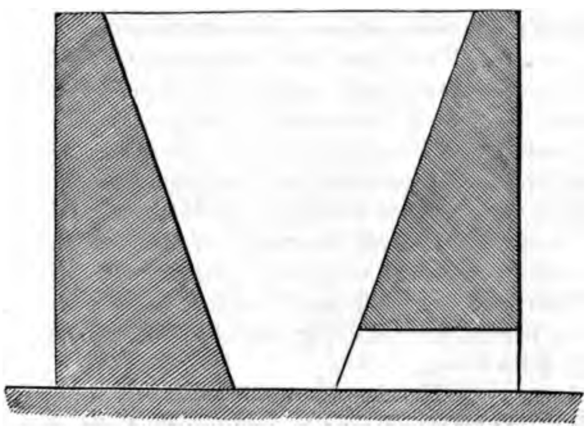


Fig. 1.

stituents, such as water, carbonic acid, sulphur, and organic matter. By this process also, any protoxide of iron that may be present is converted into peroxide. Generally it is advisable to calcine ores of the same formation together; but if any particular sample contains much sulphur, it will be better to calcine it by itself to avoid contaminating cleaner ores. The expulsion of *sulphur, when* present in large quantities, is facilitated *by the introduction* of a jet of steam with atmospheric

air, the sulphur passing off in combination with the hydrogen of the steam.

The calcined ore is next passed to the blast furnace, of which the *general* form is shown on Plate I.; it consists of two truncated cones joined at their widest extremities; the bottom of the furnace is called the hearth, and the lower part of the lower cone the boshes; and is constructed of fire-brick, or of a very refractory material called fire-stone. Where the two cones meet is a barrel-shaped or cylindrical belt, forming the belly. The upper cone or body of the furnace is formed by an interior lining of fire-bricks, which is enveloped in a casing made up of broken scoria, or refractory sand, whereby the internal lining or shirt of the furnace is separated from the external coating of fire-bricks. The opening at the top of the furnace is called the throat or tunnel hole, and may be open to a chimney, but is more commonly closed by a bell, which can be opened to permit the charges of fuel, ore, and flux, to enter the furnace, but at other times prevents the loss of carbonic oxide, the inflammable gases being drawn out through flues, and profitably employed under boilers for heating the blast.

Air is supplied to the furnace through tuyeres, or "the irons" terminated by nozzles through which the blast is forced. These tuyeres are cased, so that water may be circulated round them to prevent their destruction by the high temperature to which they are necessarily subjected.

The materials to feed the furnaces are usually drawn up an incline, or raised by a vertical hoist to the furnace top.

The dimensions of these furnaces vary widely, according to the character of the materials dealt with, the height varying from 36 to 80 feet, or more. The Aclam furnaces are about 70 feet high, having a diameter of 8 feet on the hearth, and 22 feet 6 inches in the widest part of the body, and the materials employed average about 6

tons to each ton of pig iron produced; the proportions being:—

	Tons.
Cleveland Ironstone	3·50
Limestone	0·75
Coke	1·30
Coal	0·50
	6·05

or about 4·25 tons of raw material, exclusive of fuel. The produce of this furnace is 300 tons to 350 tons per week.

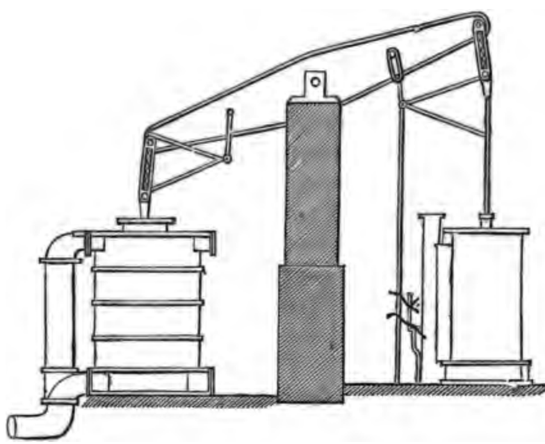


Fig. 2.

The blowing machine commonly used for supplying the blast to the furnace is shown in Fig. 2; though in latter years these engines are frequently made on the horizontal type, the steam and blowing cylinders being laid in line, so saving the beam and parallel motions. That illustrated comprises a large cast-iron cylinder, accurately bored, and provided with an air-tight piston; the cylinder is closed at both

extremities by iron covers, a stuffing-box being attached to the upper cover, through which the piston-rod passes; the whole forming a double-acting pump driven by a beam engine.

The practical working of the blast furnace is as follows: assuming the furnace to be newly erected, or what amounts to the same thing, newly lined, the masonry must not be too suddenly exposed to a high temperature, and the lighting is therefore commenced by igniting a quantity of loose fuel in the arch forming the breast of the furnace.

After some days, when the furnace is sufficiently heated, fuel is thrown in through the throat and allowed to rise as far as the middle of the boshes; when the drying is still further advanced the whole internal cavity is gradually filled up with fuel; after which the blast is gradually applied, being subsequently raised to its full pressure. When the fuel has sufficiently sunk, a small charge of ore and flux is spread over it; after which alternate layers of fuel, ore, and flux are added.

The blowing machine is usually worked by steam power, and it may be calculated on the average that one horse-power is required for every three tons of metal produced per week.

In one of the Welsh smelting-works it was found that furnaces producing 60 tons of cast iron per week consume on an average 3,600 cubic feet of air per minute; the power expended being one horse for every 2·1 tons of iron produced per week.

In charcoal furnaces, ½ lb. per square inch is sufficient blast pressure; but for coke, a pressure of from 1½ to 3½ lbs. is requisite, the average being about 2½ lbs. per square inch.

Some furnaces are worked with cold, others with hot blast; and to heat the blast of a furnace producing 60

tons per week to the temperature of 600° Fahrenheit, about 32 tons of coal will be consumed weekly, being a little more than one-half the weight of metal produced. This, however, is saved by heating the blast by the combustion of the inflammable gases drawn from the top of the blast furnace.

The cast iron produced in the blast furnace is usually run out into troughs formed in a sand bed, from the sides of which smaller troughs branch off. The slag runs over the top of the hearth into moulds or boxes, and is carted off from time to time, as soon as it is solid; and as soon as the hearth is full of "metal," it is tapped into the pig beds.

The cast iron thus obtained is very crude, and requires remelting to render it suitable for castings; if intended for the manufacture of wrought iron, it is sent to the refiners, and treated by one or other of the processes now to be described.

The bulk of the foreign matters in the iron ore is dissolved in the blast furnace by the limestone flux, and so carried away in the slag.

According to the old method of transforming cast iron into wrought, it is first heated in a refining furnace, usually built on a mass of brickwork about nine feet square, the sides of the fireplace being formed of hollow cast-iron troughs, through which water is circulated to prevent their fusion. In this furnace the metal is fused and subjected to the action of the blast, whereby a considerable portion of its carbon is oxidized and removed, and also nearly the whole of the silicon; the metal is then run out into flat moulds.

The further purification, or puddling, is conducted in a reverberatory furnace, of which a longitudinal section is shown in Fig. 3. The sole or centre part, B, of the furnace is charged with broken metal, rich clay, and iron scale;

the doors and sides of the furnace are now closed and fuel is thrown on the grate A. When the metal begins to melt, a side door is opened and the charge continually stirred, to expose fresh surfaces to the air, until it arrives at a pasty state, when the fire is lowered.

The metallic bath now appears to boil, from the evolution of carbonic oxide, which burns on its surface with a blue flame. The stirring of the mass is then continued until it becomes sandy, and subsequently of a uniform granular appearance. The iron is now said to work heavily, and a portion of the scoria runs off at C; after which the

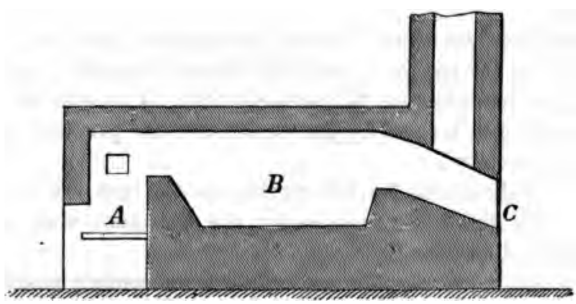


Fig. 3.

puddled iron is formed into balls, and the remaining slag expressed under a squeezer or hammer. The charge of a puddling furnace is from 3½ to 5 tons. It will be observed that in this furnace the metal is not brought into contact with the fuel.

By the Bessemer process, the impurities are oxidized out of the cast iron by forcing *through it* a current of air, as follows: the cast iron is melted and run into a converter, *of the form shown in* Fig. 4; air is then forced in through *the small passages* shown in the bottom of the vessel, the *combustion of the* impurities giving sufficient heat to

keep the metal in a molten condition. The colour of the flame issuing from the mouth of the vessel indicates the completion of the process. If steel is to be made, the iron

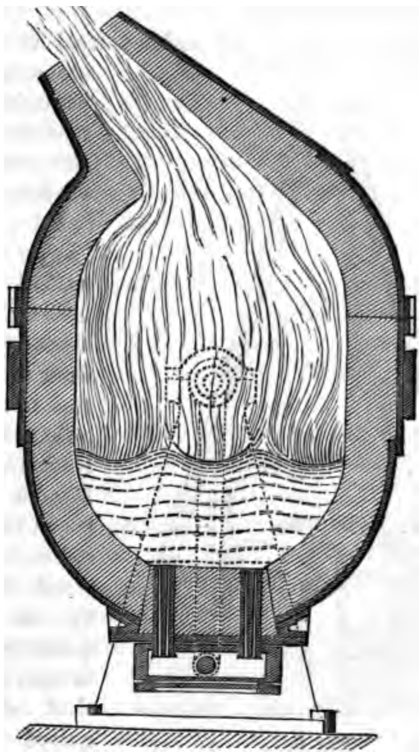


Fig. 4.

in the converter is partially *re*-carbonized, by running in a suitable quantity of a mineral (spiegel) rich in carbon, *after which* the steel is cast into ingots in suitable moulds.

It has also been proposed to use steam instead of air i

the converters, a method tried some years since by Galy-Cazalat, the idea being that on its decomposition by the heat, while certain impurities passed away combined with the oxygen, any sulphur or phosphorus present would be taken up by the hydrogen.

The ordinary process for making steel is known as cementation. The wrought iron intended to be made into steel is drawn out into bars, then cut into suitable lengths and packed in powdered charcoal in cases, which are then placed in a cementing furnace, of which a section is shown at Fig. 5, and exposed to a bright red heat until the metal has taken up a sufficient quantity of carbon to convert it into steel of the required quality. The bars are subsequently worked under a hammer until they become of uniform, or homogeneous composition.

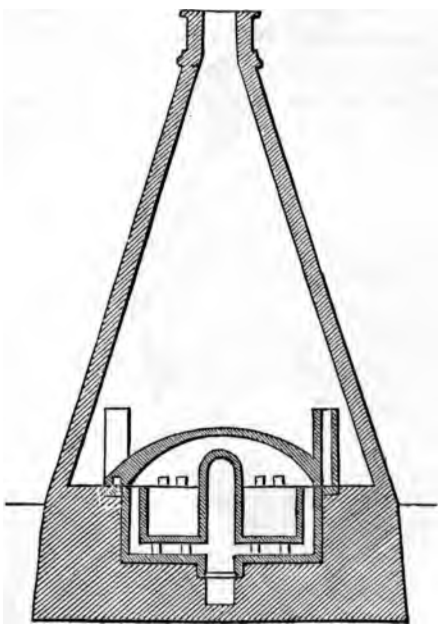


Fig. 5.

Iron half converted into steel contains one-150th of carbon.

Soft cast steel capable of welding contains one-120th of *carbon.*

Cast steel for common purposes contains one-100th of carbon.

Cast steel requiring greater hardness, but still malleable, contains one-90th of carbon.

Steel bearing a few blows, but unfit for drawing, contains one-50th of carbon.

First approach to steely-granulated fracture, contains one-30th to one-40th of carbon.

White cast iron contains one-25th of carbon.

Mottled cast iron contains one-20th of carbon.

Super-carbonated crude iron contains one-12th of carbon.

I will now pass to the consideration of the metallurgy of COPPER.

Of the various deposits of copper, the sulphuret is the most common in the whole world; and the commonest in England is the sulphuret of copper and iron upon which the extensive mines of Cornwall and Devon are principally worked.

The ore is first crushed and sifted, and subsequently washed or jigged; which consists in placing the ore in a sieve in a cistern of water, and jerking it up and down. By this means the portions of ore are momentarily suspended in the water, and are presently found to have arranged themselves with the largest pieces at the bottom and the smaller fragments above. When large quantities have to be dealt with, power-driven machinery is substituted for the hand sieve.

The round buddle used for cleansing copper ores is shown in vertical section in Fig. 6. It consists of a conical bed, on the centre of which a stream of water continually pours, where the ore is also supplied, being uniformly spread, by means of brushes suspended from arms carried by a vertical spindle.

The specific gravity of the ore in this apparatus determines its position, the richest mineral being deposited at

the centre, and the deposit diminishing in value towards the outer edge of the buddle, where a broad ring of tailings or refuse matter is taken out; the ores thus cleaned are ready for the smelter.

The smelting of copper is conducted in reverberatory furnaces, and is a complicated process, the mineral undergoing ten operations.

In the *first*, the ores are roasted or calcined in order to

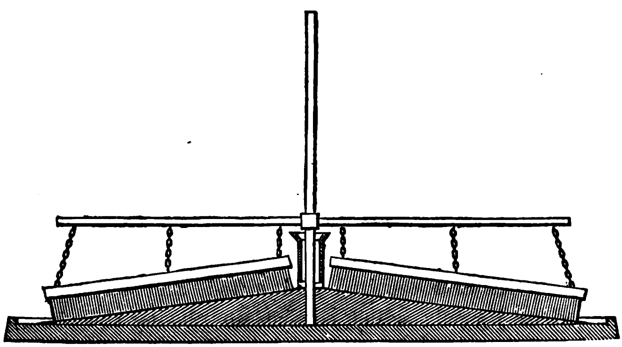


Fig. 6.

volatilize such substances as sulphur, zinc, arsenic, antimony, &c.

In the *second*, the calcined products are fused with other minerals not previously calcined; this is called roasting for coarse metal.

In the *third*, the remaining sulphur that could not be expelled by heat alone is removed by alternate exposure to oxidizing and reducing flames.

In the *fourth*, termed melting for white metal, the iron is eliminated as slag by combining it with silica.

In the *fifth*, melting for blue metal, the calcined coarse metal is fused with roasted ores rich in copper.

In the *sixth*, the slags are remelted to cause the production of a "matt," in which the copper in the various slags is brought together.

In the *seventh* a twofold object is involved,—the charge being first oxidized to decompose the sulphuret of iron into oxide of iron and sulphurous acid, the latter being evolved while the former combines with silica, and is carried off as a fusible slag. The whole mass is then melted.

In the *eighth*, roasting for regulus, oxidation first occurs, but as the fusion proceeds, the oxide of copper reacts upon the sulphuret; sulphurous acid is evolved and metallic copper or a sulphuret of copper produced. The products are three, all of which have to be reworked: a regulus containing about 21 per cent. of copper; a slag containing about 10 per cent.; and bottoms or alloys with other metals.

In the *ninth*, regulus is roasted and fused for crude metal; and—

In the *tenth*, it is refined and toughened. After fusion the scoria is taken off the surface of the metal, and a few shovelfuls of anthracite or wood-charcoal in powder are thrown on the surface of the charge; after which it is stirred with a pole of green wood for about twenty minutes, after which it has attained the condition of fine metal.

This brief summary contains the substance of the ordinary process of copper smelting.

The most common ores of ZINC are the carbonate, sulphuret, and silicate. The ores are first roasted or calcined and the zinc is subsequently distilled from them in retorts, the forms of which vary in different districts.

The TIN of commerce is obtained from the native oxide of that *metal; some* of the ores, however, require a care-

ful cleansing previous to undergoing the smelting operation. By the first process, the ores are mixed with a proper amount of powdered carbonaceous matter, and reduced in a reverberatory furnace. By the second process, the oxide is reduced in a small blast furnace worked in the usual way.

LEAD is obtained from its sulphuret, galena; which after mechanical cleansing is roasted in a reverberatory furnace, which by oxidation converts it into oxide and sulphate of lead, which, reacting on each other, cause the production of metallic lead. This often contains sufficient silver to render its extraction a matter of commercial importance.

From the foregoing descriptions it is obvious that the reverberatory furnace admits of greater range of chemical reactions than can be obtained in the blast furnace. I will now review the chemical operations occurring in the two furnaces.

BLAST FURNACE.—The first chemical change which the impure oxide undergoes in its passage from the top to the bottom of the furnace is its reduction to a porous mass of metallic iron, by the carbonic oxide gas rising from the lower layers of burning coal. The temperature of this part of the furnace is much too low to melt the iron, and it therefore sinks down unchanged with the clay and limestone fluxes until a hotter place is reached. Here the second change occurs; the clay, sand, and other impurities of the ore unite with the limestone to form a fusible silicate or slag, whilst the heated metal coming in contact with the carbon, unites at once with it to form cast iron, a fusible compound which runs down to the bottom of the furnace. This, in passing through the hottest part of the furnace, *reduces* the silica with which it meets to silicon, which *combines with the* carburetted iron.

REVERBERATORY FURNACE.—This furnace may be used

simply for fusion, for the fuel is not in contact with the materials treated, hence it may act by heat alone. Oxidation may be caused by admitting air to the sole of the furnace, where the materials are operated upon; and deoxidation by closing that part of the furnace, and so limiting the supply of air to the grate or fire-place that carbonic oxide is brought into contact with the highly heated charge.

CHAPTER II.

THE FORGE.

THE wrought iron leaving the puddling furnace is ready for manipulation in the forge. First it is put under heavy hammers, generally steam hammers, by the blows of which it is consolidated, the slag being squeezed out in fiery showers, and the "bloom" drawn out into a form which may be dealt with by other machinery.

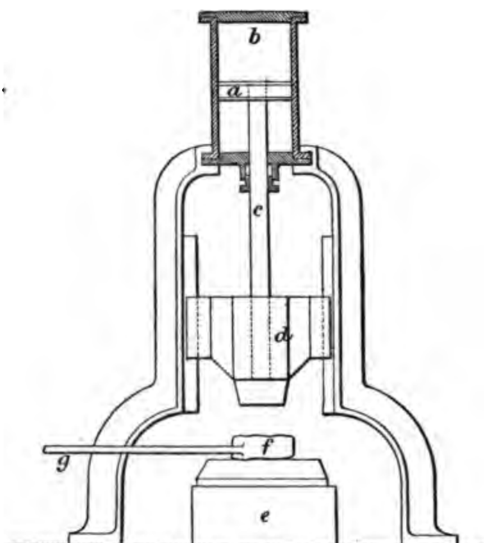


Fig. 7.

A diagram of a steam hammer in section is shown at Fig. 7. *a* is a steam piston in a cylinder *b*; to the piston *a* is attached the piston rod *c*, to the end of which is keyed the heavy "head" *d*; *e* is the anvil, firmly bedded on a solid

foundation; *f* is the bloom to be hammered, which is stuck to a rod *g*, temporarily, by which the forgeman can turn it about under the hammer. The steam being admitted under *a* the piston rises, lifting the head *d*, which falls on the steam being allowed to escape from under *a*; and its fall may be accelerated, and so the blow intensified, by admitting steam *above the piston a*, simultaneously with the escape of steam from below. For details and arrangements for admitting and emitting steam, &c., the reader is referred to subsequent chapters on the "Details of Steam-engines." These hammers admit of being regulated to the greatest nicety of blow, notwithstanding the immense force exhibited, and with one a bottle may be safely corked, or a nut cracked without breaking the kernel.

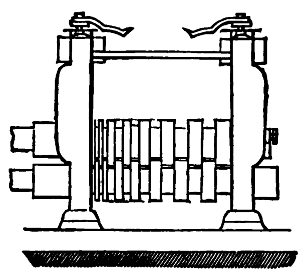


Fig. 8.

From the steam hammer the metal passes to one or other machine, according to the purpose to which it is to be applied; if to be made into plates or bars, it is carried to the rolling mills, through which it is drawn by the revolution of the rollers. Fig. 8 shows one form of bar mill. It will be observed in this arrangement that a bar having passed once through, must be carried back to the front to pass through the next smaller groove; now by using *three* rollers, the bar can go through between the top and middle rollers, and come back between the middle and bottom rollers, and so time is saved and the iron passes oftener without requiring to be reheated. These mills are made so that the rollers can be removed and changed at pleasure; they are geared with heavy toothed or spur wheels, and driven by

suitable steam or water power. The plate mill rolls are, of course, plane cylinders.

During the last 10 or 15 years the increased employment of hydraulic machinery in forges has made a marked difference in processes of manufacture, and I may say that whatever can be pressed in wrought iron *is pressed*, and the work is usually better and more expeditiously executed than by the hammering processes.

The hydrostatic press, or "hydraulic" as it is commonly called in the yard, is shown in vertical section at Fig. 9. A is a cylindrical plunger, the "ram;" B B the two sides (in section) of the cylinder, of which C is the interior. Water is forced into C through a small pipe *d*, and the ram is kept water-tight by the leather collar *e*, supported on a copper ring. This collar being hollow, the water under pressure flows into it, forcing it on one side against the ram and on the other against the inside of the cylinder, and so preventing loss of water and pressure. In some hydraulics, hemp packing has been found to act perfectly. An idea of the pressure obtained from a press of this description is afforded by the following calculation. Let the ram be 6 inches in diameter, then its area will be $6 \times 6 \times \cdot 7854 = 28{\cdot}274$ square inches; the supply pump being 1 inch diameter and pressed with a force of 1,000 lbs. (either by hand lever or by steam power), the pressure per square inch is $\frac{1000}{\cdot 7854} = 1{,}276$ lbs. per square inch (nearly). *This, multiplied* by the area of the ram, gives for the total *pressure on the* latter, $28{\cdot}274 \times 1276 = 36{,}077$ lbs., or

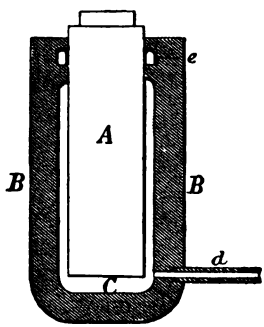


Fig. 9.

upwards of 16 tons. A good example of the use of "hydraulics" is found in the forging of railway wheels. In making solid tyres of iron or steel (that is weldless), the bloom is first worked under the hammer into a cheese shape, it is then punched, and is then in the form of a very thick ring. This ring is now put in a mangle of two rollers on vertical shafts, one roller is *inside* and the other *outside* the ring; these rollers, properly shaped to form the inside and outside of the tyre, are pressed together by "hydraulics," and as they revolve the ring between them becomes thinner and of greater diameter until that required is reached. Of course the tyres are pressed hot. By hydraulic pressure also bars are bent up to form the spokes, and the wheels when complete are pressed on to the axles. In hydraulic presses also are shaped angle and tee iron knees; flat plates are dished or buckled to form floor plates for bridges; railway waggon hooks and numberless other articles are pressed into the required forms.

The soundest and best railway axles are made of V-shaped bars, piled together so as to form a cylinder, and then welded in rolls at a white heat; the wedge-like action occurring secures a sound weld which cannot always be relied on when square bars are piled for welding. The question of heavy welds has always been a troublesome one, the difficulty being to know whether the weld *is* sound when made.

About three years since, a method of testing the solid continuity of iron was discovered and experimented on by Mr. S. M. Saxby, R.N. When a small magnetic needle is passed slowly in front of a bar of homogeneous iron laid east and west, the needle will not be disturbed. If, however, the iron is not uniform, or has flaws in it, its effect on the magnetic needle varies, and instead of the attractions balancing each other, they vary with the condition of *the iron,* and varying deflections of the needle occur, to

right or left as the case may be, but any such deflection indicates a defect in the iron tested.

By this method Mr. Saxby indicated the weakest points in a number of bars, and on those bars being subsequently broken in the testing machine, the predictions of the needle were in every case verified. I do not know that this process of testing has come into general use in any locality at present, but it certainly deserves to be widely known, as it is so simple and ready of application, a pocket compass being all that is needed for the most searching investigation.

From the heavier work of the forge, we pass to the smaller operations of the smith's shop. Here, instead of dealing with the blooms from the ball furnaces, and the ingots from the Bessemer converter, smaller articles are made from bars, plates, and "uses," the work being done almost entirely by hand, though a light steam or pneumatic hammer is a valuable adjunct to the smith's shop.

The iron to be worked up is heated on an open fire of small dimensions, the heat requisite being maintained either by bellows worked by hand, or by a fan or blower when a large number of fires are going at once.

Coal of a suitable character must be selected for the fires; the best for the purpose is a strong, dense, durable coal, possessing a good body, and dull and dirty in appearance. Bright, easily broken coal is not good for this purpose, and such matters as tend to combine with the iron and form clinkers are very deleterious; sulphur especially being an element to be avoided in forge fuel.

The forge fire-place is made about 8 or 9 feet square, of brick. The tue iron supplying the blast is at the back of the fire; the whole being surmounted by a hood and chimney to carry off the smoke and heated air.

The iron is worked upon a stout mass of iron called an

anvil, shown in Fig. 10. It rests on a large block of wood which raises it to a convenient height, and at the same time deadens the vibrations arising from the blows upon it. The metal to be shaped is beaten by sledge or hand hammers of suitable weight according to the size of the work, dies or swages being used where requisite to produce any particular form. The bottom swage is, by means of a tail, fitted to an aperture in the anvil, the iron to be wrought is placed on it, and the top swage being put upon the iron, is struck by the hammer, and so on until the "use" is brought to the required form. The upper swage is held by a light hazel rod, which prevents the shock of the hammer from producing any strain upon the hand of the operator. Some swages, a swage block, and a sledge and hand hammer, are shown at Fig. 11.

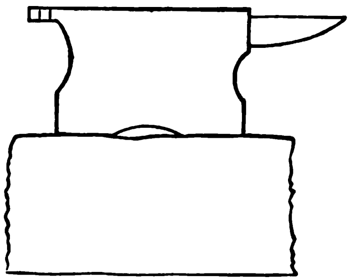


Fig. 10.

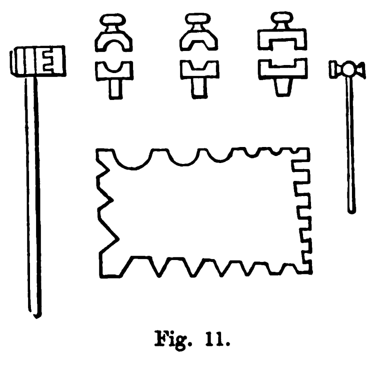


Fig. 11.

When iron is being welded a flux must be used to prevent the oxidation of the surfaces to be united; for this purpose fine white sand and common salt may be used. The iron *is heated* and dipped in the flux, and replaced in *the fire until it* has attained a white heat. The flux has

then fused over the surface and dissolved any oxide of iron that may have formed; the two surfaces to be joined are then laid together and struck continuously, working from the centre towards the edges so as to expel the flux and insure a perfect union of the metal.

Improvements in machinery and new inventions have entirely revolutionized the old system of smithing: for instance, bolts, nuts, and rivets, that used to be made by hand, are now turned out in great quantities by machines specially made for the purpose; and the closing up of the rivet-heads is also done by machinery, on all work executed in the yard, except irregular parts and details of unusual character. Of course in the erection of girders and other similar work, hand riveting must still be almost entirely relied upon.

Probably a chain requires more careful examination for flaws than any other piece of work turned out from a forge, as it necessarily depends throughout, for its strength, upon the soundness of the welds in the links. A few years back a chain made of the best quality of iron and tested at a proving works, before use (in a hoist) broke at a much lower strain than that to which it was tested, and this breakage is thus to be accounted for. There was in one link a defective weld, and so long as the link adjoining did not touch at that weld, the faulty link was strong enough to hold the load, *acting only as a hook,* but by some working of the chain the bearing of the link next to the faulty one came upon the defective weld, which then opened, letting the chain asunder. In this case luckily only material damage ensued.

The link that broke did not snap through brittleness, for half of it was afterwards hammered out straight, *cold,* without cracking, so that no doubt remained as to the *nature of the* breakage.

The lesson to be learnt from this is, always to test a

chain by fire as well as by the load test of the proof-house. The chain should be passed through a smith's fire and examined link by link, being made red hot and then quenched by water, when a faulty weld or "shut" will almost invariably show itself. The magnetic test cannot, for obvious reasons, be applied in this case, the work not being in the form of a continuous bar.

Smith's work is probably the least suitable for description on paper, but I have here endeavoured to give as clear an idea of the leading processes as the nature of the manipulation will admit; the facility of working can only be acquired by the actual use of the tools.

The forging of copper is a special trade exercised by coppersmiths, and therefore cannot be regarded as forming properly a branch of mechanical engineering. I will here only remark that it is worked at a much lower temperature than iron, and if worked cold requires frequent annealing.

CHAPTER III.

THE FOUNDRY.

A GREAT variety of work is executed in cast iron, the details being made by pouring the metal when in a molten state into moulds suitably formed to receive it. These moulds are made in green sand, baked sand, and loam, according to the nature of the work in hand; and in some cases the mould is partially of iron, where the casting is to be "chilled," in order to produce extreme hardness.

The general process of casting is as follows:—Two boxes without either top or bottom, called flasks, are so made that one will fit to the top of the other, being kept in position by pins attached to its sides, which fit into corresponding holes in the lower flask. The bottom box being set on the foundry floor is filled with sand, and the model or pattern of the object to be cast is partially imbedded in it. Say this is a ball, it will be half its depth in the sand, which is to be smoothed off level with the top of the box; the whole is then dusted over with coal dust or charcoal (to prevent the adhesion of the sand to be added above), and the top box adjusted by the pins to the bottom one. Sand is now filled in on the top of the pattern, but two tapered pegs are put in resting on the pattern, so as to form channels; one (the lower) will be that through which the liquid metal will subsequently be poured in, the other being for the escape of air as the mould fills. The sand being properly rammed, the upper box is lifted off with its contained sand, and forms the upper half of the mould;

the pattern is then lightly tapped to loosen it and is withdrawn from the bottom box; the tapered pegs are also removed, leaving the passages or "gits" open; the top box being now replaced on the lower, fitting by the pins and held down by pegs passing through them, the mould is ready for use. The molten metal must be poured into the git opening into the lower part of the mould until it runs out of the upper git, thus showing that the mould is full; scales and impurities will also rise to the top and escape by the git if it is sufficiently high, and this should be made so as to give a "head" of metal of weight enough to press that below it into a uniformly solid mass free from air holes and honeycomb.

The casting will of course shrink as it cools, hence allowance must be made for this contraction by making the model larger than the required casting; the requisite quantity is one-tenth of an inch per foot for iron (a casting 5 feet long would require a pattern 5 feet ½ inch long), and one-eighth of an inch per foot for brass, in every direction.

The example I have taken above is chosen for its simplicity, but more often the preparation of a mould is a complicated piece of work, requiring no small degree of skill on the part of the moulder, in mending and trimming the mould after the pattern is removed, which he does by means of special tools that require to be handled with care and delicacy, reminding the observer in some degree of the work of the sculptor.

The drawing of a piece of work being furnished, let us follow it to the pattern-maker's shop. Pattern or model making is a trade by itself, and must not be confounded with carpenter's or joiner's work. The pattern-maker uses a rule *properly graduated*, to allow for the contraction of the castings, *so it is* important, in order to prevent mis-*takes, that all* dimensions be *figured on the drawing*, so that

he *reads* these dimensions and sets them off on his material with the proper rule—which, however, will not do to measure on the drawing with; and if two rules are about the bench, one for the drawing, the other for the work, it is very easy to mistake one for the other.

When a pattern is made all the internal angles must be filled up and rounded off neatly with a composition which may be made of wax and burgundy pitch, for if these re-entering angles be left the casting will be likely to crack at those places; in the cooling of the casting such angles will have a tendency to shrink still farther in, thus forming, as it were, so many notches in the object, through any of which it may be snapped by comparatively small force.

In large patterns instead of the composition, which is sufficient for smaller work, the corners must be filled in with suitable fillets of wood neatly hollowed out, so as to leave rounded internal angles.

The pattern-maker must bear carefully in mind that the pattern must be so made as to *come easily* out of the sand, so in some cases it may be necessary to make it in pieces in order that it may be taken out in parts; thus, if the pattern has projections on the ends near the bottom, for instance, by first taking out the middle the ends can be brought together, and the projections thus cleared from the mould. Holes through, and cavities in castings are formed by inserting "cores" in the mould, such cores being held at one or both ends in recesses in the mould, made by projecting pieces called "core prints," or shortly "prints," on the pattern.

Suppose the poppet-head of a lathe is to be cast. It is of the form shown in Fig. 12, consisting of a hollow cylinder supported on a stand, having an opening in the centre of its base for a bolt to secure it in any required position. There is also an opening in the cylindrical part

for a set screw. The form of the pattern when made is that shown at Fig. 13.

The *detailed* process of moulding is as follows:—Two flasks being at hand, one furnished with pins and the other with ears or lugs having holes in them to receive the pins, the latter is taken and placed lugs downward upon a smooth slab, and filled with moulding sand which is firmly rammed down. The flask may then be inverted, the sand being retained in the frame by its cohesion and adhesion to the sides of the flask; but when the latter is large it is for greater security furnished with transverse bars. After the frame has been inverted the upper surface presents a smooth and level surface, and in the centre of this is

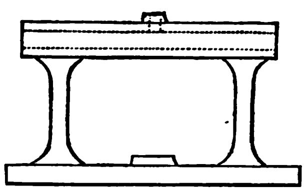


Fig. 12.

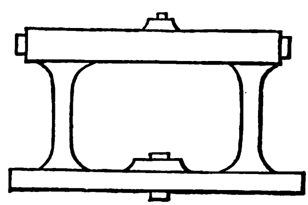


Fig. 13.

scooped a hollow resembling the form of the article to be cast. In this the pattern is bedded in a horizontal position, being sunk in the sand to, as nearly as possible, half its thickness; powdered charcoal or coal dust is now sprinkled over its whole surface, and the upper flask adjusted in position, it is then filled up with sand which is firmly rammed around the pattern. The flasks can now be separated, the adhesion of the sand in the two boxes being prevented by the layer of coal dust above mentioned.

The impression formed in the sand of the upper flask is smoothed and repaired where necessary by suitable trowels. The *sand placed* in the first frame is now broken up, the *frame which* served as the top of the flask is placed with

the cavity uppermost, the pattern is placed in the cavity, the empty frame fitted on, and the whole fitted up as before; but pegs are put in to form the gits in the top flask. The flask is again opened, the pattern removed, and the cores placed in position; the two parts of the flask are again closed, after seeing that the mould is perfect, and secured by pins or wedges, and the casting may then be made.

The cores are made of tough loam mixed with straw or other fibrous material and properly dried in an oven. When the cores are very long they are supported by iron bars running through the centre; and in some cases—as, for instance, water-pipes—the cores are intermediately supported by very broad-headed nails resting on the bottom of the mould; such nails are enclosed and remain in the metal of the casting.

When the casting is sufficiently cool the mould is broken up and the superfluous metal knocked off, and when the casting is *quite* cool the false seams formed at the junctions of the mould are chipped off, the cores cleared out, and the hard sandy coating rubbed smooth with a hard piece of oven coke.

Ample space for egress of gases must be allowed, wherefore it is desirable to pierce the sand to within a small distance of the cavity with a stiff wire, and also to form a sufficient number of gits. The sand should be of open texture, but of a binding character, otherwise the casting will be apt to "scab;" that is to say, there will be a liability in the sand to scale off the surface of the mould, and remain on that of the casting. If sufficient egress be not allowed for the air, blow-holes will occur within a short distance of the surface of the casting, materially reducing its strength.

In order to consolidate the casting and allow space for *all the scale to float* to the top a good head should be put

on; that is, the gits should rise considerably above the top of the casting, and all long articles, such as columns, should be cast vertically.

If the sand is used too damp, hard places will occur in the castings, which will add to the difficulty of subsequently turning or planing the work.

The above process is moulding and casting in green sand. I now come to baked sand moulding, which is conducted in a similar manner, but the sand is used in a more moist condition, the mould being subsequently dried in an oven.

If any surface of the casting is to be "chilled," an iron side is then inserted in the mould; and if the casting be large this may be made hollow for the circulation of water.

Moulding in loam is altogether different from the foregoing processes, no pattern being used at all in this method. I will take for an example the moulding of a hemispherical pot.

A cast-iron ring is laid down on the foundry floor, and upon this a brick dome roughly approaching the internal form of the pot is erected, an aperture, however, being left at the upper part. A quantity of loam formed of clay, water, sand, and cow-hair, after having been reduced to a paste, and thoroughly kneaded in a pug-tub, is laid on the brick dome with trowels and smoothed with the hand. A fire is then lighted within the dome by means of apertures left on the cast-iron ring.

A stratum of fine loam is put over the first layer and formed to the exact contour of the interior of the vessel by means of a scraper of suitable form, attached to a vertical spindle passing through the centre of the dome, and supported in bearings at the top and bottom so that it can be caused to revolve truly on its centre. The required form having been obtained, the scraper is removed and the

mould allowed to dry; after which it is thickly painted over with a mixture of water, clay, and charcoal, applied with a brush; another layer of fine loam is then applied, equal to the thickness of the required article, and to it is imparted the exact form of the exterior of the article, also by means of a scraper. The whole is then again dried, the spindle being removed and the hole at the top of the dome closed up. The mould is again painted as before.

Another ring is now laid down around the former and adjusted to it by steady pins; the mould is then covered with a layer of fine loam, followed by a thicker layer of coarse loam, and surrounded by brickwork.

We shall now have an interior dome and an exterior shell, containing between them a quantity of loam corresponding to the thickness of metal in the required vessel.

The outer shell is removed by lifting the outer ring by means of cranes, the paint coating of charcoal-paste preventing its adhesion to the substratum. It is repaired where necessary with trowels, as is also the surface of the interior dome after the intermediate layer has been broken away. Gits are prepared in the outer shell, which is replaced, and the metal is cast. As soon as the casting has become sufficiently cool the brickwork of the interior dome is loosened in order to allow of the free contraction of the casting.

All moulds having the form of solids of revolution can be thus produced by scrapers, but other forms must be obtained by the aid of templates and cores.

It is usually said that pieces can be burnt on to castings, but although this is practised it is not reliable. The casting on which the piece is to be burnt is heated nearly to its melting point, and then placed in the mould of the piece to be added, which is cast on; but as a rule, either the additional piece does not hold, or the original casting

cracks in cooling, so either way it is a process to be avoided.

Careless moulding and casting naturally lead to defective work, spongy castings, cores out of place, &c., &c., and unfortunately in some of the foundries of lower standing (for we cannot believe that any *honest* man would permit such a course), the defects are hidden from view by a fraudulent filling up of blow-holes and painting over the surfaces; and it seems astounding that this practice has become sufficiently common for there to be a well-known if not recognised name for the trashy composition used thus to deceive the purchaser, that name being "*beau monteague*," of which so much has been recently heard in connection with the failure of the Tay Bridge, which fell at the end of 1879 with such disastrous loss of life and property.

If patterns are intended to be kept in stock for future use they should be carefully painted or varnished, and this will prevent their becoming warped by contact with the damp sand of the moulds.

Toothed wheels are now cast with only a partial pattern, such pattern being made to include three or four teeth only; then, by means of a suitable machine, the teeth all round the periphery of the wheel are consecutively moulded upon this segment. By this method a very accurate mould is obtained, with also a considerable saving of time.

The mould being properly prepared, we now proceed to the process of CASTING.

Iron, as it comes from the blast furnace, is too crude to produce good castings, and requires remelting, in order to render it finer; and up to a certain point, dependent upon the quality of the metal, each melting improves it. For large *castings* the iron should be melted in a reverberatory *furnace; for* smaller work, a small kind of blast furnace.

called a cupola, is used. This consists of a low brickwork foundation, upon which a sheet-iron cylinder is placed vertically, this is lined with refractory material, and surmounted by a low chimney or conical hood; holes are formed in the side through which the blast is admitted, and others to allow the molten metal to be drawn off. The blast should consist of a full volume of air at moderate pressure, 4-inch diameter nozzles being a convenient size. The fuel and metal are supplied in alternate layers, and the metal as it melts accumulates in the bottom of the furnace, whence it is drawn as required. The charges are in the proportion of 1 of coke to 4 of iron, and the latter begins to melt about twenty minutes after its introduction to the furnace.

For large and heavy castings the moulds are sunk in the foundry floor, and the metal run into them from the cupolas or reverberatory furnace along channels in the sand of the floor. For smaller castings the metal is carried in ladles lined with refractory clay. These ladles are called shanks, and are especially made, having cross handles to facilitate their being tipped; the larger ones are moved by means of cranes.

The best castings show when broken a dull grey, granular fracture; but in each locality experience alone will show how to obtain the most satisfactory work, and it will commonly be found that mixtures of different irons are preferable to iron of one description. Good iron will stand the following test:—A bar 3 feet 6 inches long, 2 inches deep, and 1 inch wide, being placed on supports 3 feet apart, and loaded in the centre, should not break with a less weight than 26 cwt. I have known samples of iron to stand upwards of 32 cwt.; but this quality is not usually in the market.

Every casting requires more metal than is necessary to *fill the mould, the* excess going to form heads and false

seams, &c., and besides this, there is an actual loss of about 6 per cent. of the metal, so that after deducting all losses, each hundredweight of coke melts about 3 cwt. of iron, as weighed in finished castings.

The following are the dimensions of an average-sized cupola, capable of melting five tons of metal at one time. Height, 9 feet; external diameter, 5 feet; internal diameter, 3 feet 6 inches; diameter of nozzles, from 3 to 5 inches; speed of fan, 700 revolutions per minute, which will absorb a power of three horses.

CHAPTER IV.

MACHINE AND HAND TOOLS.

IN the present chapter I purpose describing the various tools used in the working of metal and other materials, with which the mechanical engineer is concerned.

FILES have forms too well known to require any detailed description in these pages. The teeth are produced by making a series of cuts with a chisel along the whole length of the file, and dividing the ridges thus raised into teeth by other cuts crossing them at an angle, after which the tool is hardened and tempered. After hardening by plunging when red hot into water, the file is tempered by dipping in oil and holding over a fire till the oil burns off. In cutting square and flat files, it is usual to leave one side smooth, so that it can rest against the work without injuring it, forming thus what is called a safe edge. A file cut only in one direction is called a float, and a rasp has numerous isolated points raised on its surface. The varieties of files are almost endless, depending as they do upon the nature of the work for which they are required, but only a few of these are necessary for the work which we have to do. These are divided into three classes: taper, hand, and parallel. The first taper to a point, the second have the sides nearly parallel, and the third quite parallel; they are also distinguished according to the fineness of their teeth, as rough, bastard, second-cut, smooth and dead-smooth. *Taper files vary in* length from 4 to 24 inches, are rect-*angular in section,* and rounded in width and thickness.

Hand files are more parallel in width and less taper in thickness than the foregoing, and are commonly used for flat surfaces where more accuracy is required than can be obtained with taper files.

Cotter files are used for filing grooves for cotters, keys, and wedges, they are narrower than hand files and nearly flat on their sides and edges. Pillar files are similar to hand files, but much smaller, varying from 3 to 10 inches in length; they are usually formed with one safe edge.

Half-round files are circular on one side and flat on the other; these and round files, which are usually taper, vary from 2 to 18 inches in length. Square files, ranging between the same lengths, are usually taper, with one or two safe edges. Crossing files are circular (segmental) on both sides. Triangular, or three-square files, are made from 2 to 16 inches in length; they are used for internal angles, clearing out square corners, and for sharpening saws.

After being used some time, files without being actually worn out become dull, the same as other tools become blunt, and require sharpening; to do this, the files must first be cleaned thoroughly, and then dipped in a solution of 1 part nitric acid, 3 parts sulphuric acid, and 7 parts water; the time of immersion will be according to the extent the file has been worn, and the fineness of the teeth. On removal from the mixture, dip in milk of lime (lime stirred into water to the consistency of cream), dry at a gentle heat, rinse with equal parts of olive oil and turpentine, and brush over with powdered coke.

CUTTING TOOLS for general use are invariably made of steel, but some special cutters are made of wrought iron, and case-hardened on the cutting edges. I shall first dispose of this latter class, among which are conspicuous rotary cutters, or discs carrying a number of cutting edges on *their faces* or periphery. The cutter is first turned and *otherwise shaped* to the required form. CASE-HARDENING

consists in converting the surface of the metal for a certain depth into steel, which part then admits of being hardened and tempered in the usual way. Procure a quantity of old leather (such as boots), and heat this in a covered pan of sheet-iron until it becomes charred and crumbles into powder upon attrition; having rubbed the carbonised leather into powder, place it in a sheet-iron box, and imbed the objects to be case-hardened in it, taking care that they are thoroughly surrounded by the closely packed powder. Make the lid of the box air-tight by a luting of clay, then place the whole in a coke fire, and keep at a red heat for two or more hours, according to the depth to which it is desired to convert the iron into steel. On removal, plunge the articles into salt water to harden; then if tempering be required, polish and reheat in a sand bath until the proper temper, indicated by the superficial colour, is reached.

The burnt leather may be replaced by other materials, for instance, 3 parts prussiate of potash to 1 sal ammoniac; 2 parts sal ammoniac, 2 bone dust, and 1 prussiate of potash; bones, urine, and night-soil are also used for this purpose.

A simple method of case-hardening when only just the surface is to be converted, is to sprinkle powdered prussiate of potash over the metal at a bright red heat, and then plunge into water, but it is very improbable that the coating of steel thus produced is even continuous.

Having touched upon the subject of hardening and tempering, it will be as well to treat the subject before proceeding further.

Hardening is performed by dipping a steel article at a red heat into some cooling medium, as water, which should contain salt, and in which the article is to be moved rapidly about to prevent a film of vapour from adhering to its surface, and so retarding the cooling influence of the water, for to the rapidity of cooling is due the hardness of the

body operated on. The metal will now be quite hard and too brittle for use, and must be subjected to the process of TEMPERING, which consists in re-heating to a certain degree according to the softness required; this is done after brightening up the surface by placing the article over a fire, or on a hot mass of iron, until the film of oxide formed on the bright part shows a certain tint. Or oil, or other matter burning at a known temperature, may be placed on the article and burned off. With ordinary tools only the ends are first plunged in the water, then rubbed with stone, and the heat descending from the metal behind tempers them; as soon as the proper tint is observed the whole must be quenched in water. The following are the surface tints and temperatures proper for various articles, the temperatures being Fahrenheit. Pale straw 430°, for lancets, &c.; dark yellow 470°, for razors, penknives, &c.; clay yellow 490°, for chisels and shears; brown yellow 500°, for adzes and plane-irons; very pale purple 520°, for table-knives; light purple 530°, for swords and watch-springs; dark blue 570°, for small fine saws; blue 590°, for large saws; pale blue 610°, for saws the teeth of which are set with pliers.

Springs may be tempered by burning off in oil.

The CUTTING EDGES of the various tools must be formed to angles, which vary according to the nature of the material to be worked, and the mode of application of the tool. Scrapers have their edges contained between facets making together an angle of from 55° to 60°. As a general rule, the softer the material, the more acute may the angle of the cutting edge be, and the angles vary for copper, brass, iron, and steel, from 55° to 90°, those for iron varying between 85° and 90°. Great care must be taken to obtain the cutting edges well defined, or their action will be unsatisfactory. The vertical section of the *edge, that is, the* section at right-angles to the edge, must

be bounded by *straight* lines, for it is evident that if these lines are rounded, the edge itself cannot get at the material properly. In Fig. 14 are shown two views of a cold metal chisel having a wide edge. This is a percussive instrument, being placed upon the work and driven by a hammer, so chipping down the surface as required. These are ground on both sides as shown, the angle of edge being 70° to 80°, and for some particular purposes even more obtuse; they are tempered down to a deep straw colour; when in use it is held in the left hand, being driven by blows from a hand hammer held in the right. A similar form of chisel, held by a hazel rod, and driven by blows of a sledge hammer,

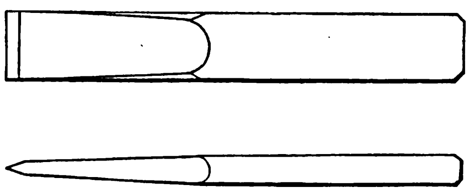


Fig. 14.

is used by smiths for cutting hot iron; but it is shorter and of stouter make, having a wider edge.

Small hand-punches, employed for piercing thin metal, are formed of round steel, tapered off and ground flat at the end. Centre, or marking punches, used for marking work where holes are to be drilled, produce a conical or countersunk recess, being formed of round steel, taper and ground to a conical point, having an angle of about 80°. Scrapers are made in two forms, as shown in Fig. 15. The first is made of an old parallel file by grinding off the teeth and grinding the end smooth, so as to form a scraping edge; the second is made of an old three-square file, by grinding the faces convex near the end, thus forming three scraping edges, each with an angle of 60°. I may here

mention among fitters' tools the metal saw, consisting of a thin narrow blade stretched tightly in an iron frame; these saws require frequent sharpening.

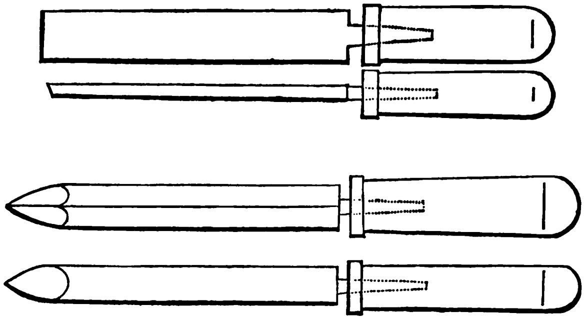


Fig. 15.

Small drills worked by hand are in constant requisition. They are of two sorts: those that are worked with an alternate reciprocatory motion, ground on both sides so as to *scrape* equally well in both directions, as shown at *a*, Fig. 16, and those worked with a continuous circular motion, ground on one side only, as shown at *b*, so as to *cut* in one direction. It will be seen that the first-described drill only scrapes, whereas the second cuts, hence produces better work. Drills of the first description are usually fixed in a shaft, having a conical tail which rests in a countersink in a breastplate worn by the operator, and through which he puts the requisite pressure on the drill. Upon the shaft is fixed a sheave or pulley, around which the string of a steel *bow passes*; by moving the bow backwards and forwards

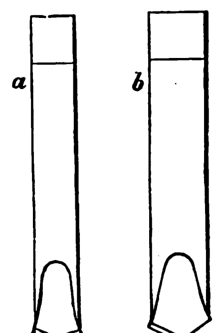


Fig. 16.

the drill is caused to rotate alternately in opposite directions, thus piercing the material operated upon.

The second class of drill is usually employed, either in a common crank brace, as shown at *a*, Fig. 17, or in a ratchet brace *b*, when the position of the hole does not allow room enough for the revolution of the crank. The ratchet brace consists of a stout shaft furnished at one end with a socket to receive the tang, or tail, of the drill, and at the other with a screw, on the head of which is a hard conical point, and by means of which the requisite pressure is imparted to the drill; in the centre of the shaft is a ratchet-wheel firmly fixed, and embraced by the forked end of an arm or lever, furnished with a pall or catch, pressed upon by a

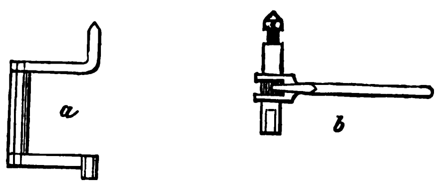


Fig. 17.

spring which causes it to fall into the teeth of the ratchet-wheel; thus when the arm is moved in the direction in which the drill is made to cut, the pall catches in the teeth of the ratchet-wheel and drives the wheel forward, but on reversing the motion, the pall slides over the teeth, leaving the drill stationary.

A great variety of minor drill stocks have been devised, but they are rather applicable to the light work of the clockmaker than to the requirements of the mechanical engineer. There is a class of scraping tools known as broaches, or rhymers, employed for cleaning out circular holes; they consist of taper, triangular, square, hexagonal, or octagonal tools, of considerable length in comparison to diameter.

Square holes are cleared out by means of drifts, made of tapered steel bars on which cutting edges are formed, by filing notches round them at regular intervals. A drift is forced through the aperture to be cleared by striking it with a hammer, and great care must be used to strike the drift fairly in the line of its length, or, as these tools are very hard, breakage will ensue.

I will now describe the production of hand-made screws, a process which is occasionally called into requisition in executing repairs.

For the smallest screws a plate of dies called a screw-plate is employed; it consists of a plate of steel in which threads have been cut, which are at certain parts filed away

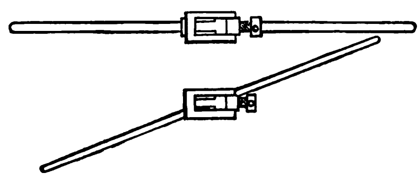


Fig. 18.

in order that cutting edges may be formed, and also to afford an outlet to the metal removed from the "blank" being cut. By this apparatus the threads of the screw are partly cut and partly *squeezed up*, and therefore not so strong as those produced by cutting with a point tool; hence on no account are *die-cut* screws to be used in places where they will be under longitudinal strain, and engineers should be careful to see that they are *not* so used, their cheapness tempting dishonest persons to substitute them for the proper article.

For the production of larger screws such as threads of bolts, dies made in two or more parts are used, the cutting edges appearing on the edge of the dies; these dies are *used in a stock*, of which two forms are shown in Fig. 18.

In the middle of the stock is a rectangular opening containing V-shaped ridges, which fit grooves on the dies and retain them in position. At one end of the rectangular opening the ridges are cut away to allow of the introduction of dies as required, which are adjusted by means of a set screw formed on one handle, or preferably as shown in the second form.

The threads in nuts or female screws are cut after the nuts are drilled, by taps formed as follows :—Upon a piece of the best round steel, accurately turned, a screw is carefully cut, so as to be true throughout; a portion of this thread is then removed by filing three or four grooves along the sides of the tap, cutting edges being thereby formed and space left for the escape of metal cut away from the blank nut; the thread is also reduced towards the end of the tap, giving it a tapering form, so that it may easily enter the work, and gradually cut the thread without straining the material acted on or the tap. Usually a set of taps comprises three for each size, two taper and one plug or parallel tap for finishing; they are made with square heads to fit a stock or tap wrench, which is handed round in the same manner as a die-stock. These tools are lubricated with oil to prevent their becoming heated.

Shears are used for cutting sheet metal; their blades are very broad in proportion to their length, and their edges are ground at an angle of 85°.

I now come to tools used in conjunction with machines for working metal. Most of these tools are forged from square steel, and shaped, hardened, and tempered according to the purposes for which they are required. Fig. 19 shows a point-tool used for turning, planing, and shaping. This tool produces a surface consisting of very narrow grooves close together, the metal being removed by the action of the point and one side of the cutting edge. Another tool, derived from that just described, is most

frequently used in the lathe for taking large cuts when there is a great amount of superfluous material to be removed; it may be said to consist of one side of the point-tool, the whole of its cutting edge being inclined to the work. Fig. 20 shows the spring tool, which, being formed

Fig. 19.

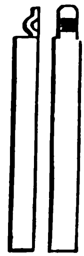


Fig. 20.

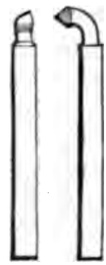


Fig. 21.

with a bend or spring in it, yields to any hard place, instead of tearing it out after the manner of the point-tool; it is broad, and rounded slightly on the edge to prevent its corners from digging into the work. This tool gives a better finish, but less accurate work than the point-tool.

The side tool, used for boring small cylinders, and cutting internal screws, is shown in Fig. 21; it is the point-tool bent to one side.

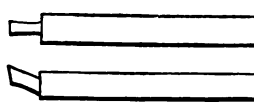


Fig. 22.

Fig. 22 represents a parting tool, used for cutting through or dividing work; it is made widest at the cutting edge in order that the metal behind may not come in contact with and jam in the work against the sides of the cut. A similar tool is used for cutting square-threaded screws; one, more the shape of the point-tool, being used for V threads.

At Fig. 23 are shown a number of hand tools used with

the lathe; *a* is a graver; *b* a flat tool capable of springing slightly; *c* an external, and *d* an internal screw tool. Fol-

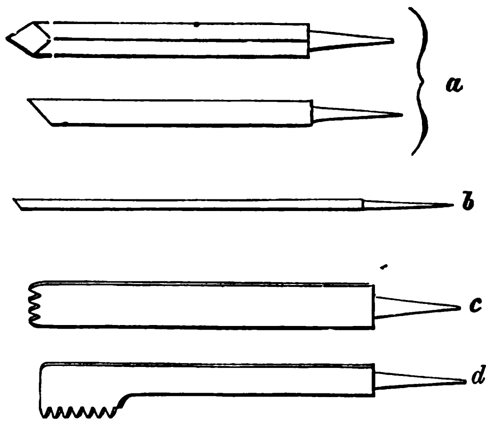


Fig. 23.

lowing the points of these tools are threads determining the pitch of the screw being cut.

Fig. 24 is a slotting tool, which acts vertically, being fixed in the vertical moving bar of the slotting machine, and acting end on. It is chiefly used for slotting out the keys in wheels, to receive the keys or wedges by which they are secured to their shafts.

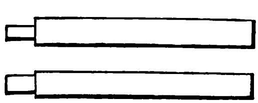


Fig. 24.

There are many other tools used with machines slightly differing from the generic forms given above, but being identical with them in principle, require no further description.

There are numerous small tools used in the lathe and drilling machine, principally for boring purposes; some of these are shown at Fig. 25, the remaining sketches in this

figure showing some forms of drills used in the lathe and drilling machine. Machine drills are ground to *cut one way* only.

Face and edge cutters in great variety are employed for grooving and trimming work; they are made by raising a number of ridges or cutting edges on the surface or periphery, as the case may be, of a blank disc. Punches, shearing edges, taps, &c., used in machines are similar in their general forms to the same tools used by hand, but

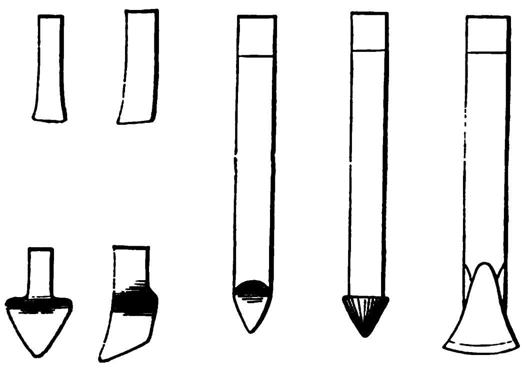


Fig. 25.

stronger. The taps used for making screw tools and worm wheels are called hobs.

My space will not allow of my illustrating separately all the different forms of machines used in the works of the mechanical engineer without encroaching too much upon that more imperatively demanded by the work he produces; so I must be content to give a general description of the principles on which they are designed, illustrating a few of the distinctive features characterizing them.

There are two principal parts in every MACHINE TOOL, *the part which holds* and directs the cutting tool, and that

which holds and presents to its action the work to be operated on: between these intervenes the mechanical arrangement by means of which the work is moved onward as the operation proceeds, so as to offer fresh surfaces to the action of the tool; this motion is called the FEED. The

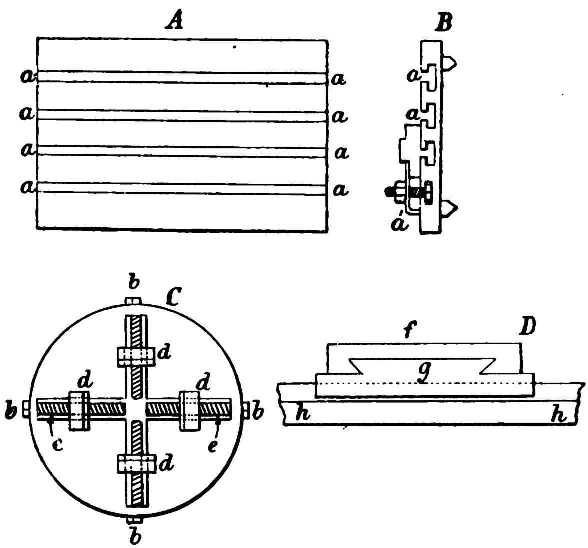


Fig. 26.

tool is carried in a box or REST, and the work securely fixed on a table or CHUCK.

The general forms of chucks will be understood by a reference to Fig. 26. A shows a plan and B an end view of the table of a planing or shaping machine; it will be seen that it is made with undercut or T-shaped grooves, *a*, into which may be slid the heads of screw bolts by means of which the work is secured, being held by clamps or "dogs," as shown at *a'*. This table has v's beneath it,

which fit corresponding grooves in the frame on which it slides. These plates or chucks are rectangular in the planing, shaping, and drilling machines, circular for the turning lathe and the slotting machine. C shows a lathe chuck to which the "dogs," *d*, are fixed, being worked up to any required position by the screws *e* in the grooves *b*, so as to grip the work to be operated upon; this is called a "dog-chuck." An ordinary chuck for a lathe, called a face-plate, has rectangular holes in it through which bolts can be passed from the back to hold the work. In the illustration the screws have square heads, to which fits a key or spanner for adjustment.

At D is shown the way in which plates are fitted one upon another, either for a bed for the work or a rest for the tool. The plate *f* can be slid upon *g* by either a screw or rack motion, and in turn, *g* can be slid upon the lower bed *h h*, in a direction at right angles to the motion of *f*. By means of these two motions any required movement can be given. In the slotting machine the table is also capable of being revolved, by a tangent screw acting upon teeth on its periphery; thus it may be used as a boring machine.

The cutting tool is secured by clamps screwed down upon it. The feed may be put on by hand, but machine tools are made to act automatically at will. The lathe generally travels the tool rest by a screw called the "leading screw." It is evident that by interposing suitable wheels between the shaft carrying the work and the leading screw, that the tool may be so travelled as to cut a screw of any required pitch; but if that pitch is a greater angle than 45° the cutting tool must be laid on its side.

The feed in some cases is put on the tool, as in the planing machine and lathe; in others on the work, as in the slotting machine, and in some cases on both, as in shaping *machines*. A common form of feed motion is shown at

Fig. 27, where *a* is a toothed wheel on the end of a screw moving the tool or table as the case may be; *b* is a pall which will *slide over* the teeth in one direction, but catch and push the wheel on when moved in the other; its position is maintained by a link acting about the same centre as the wheel *a*, and motion is given to it at every stroke or revolution of the machine through the link *c*, connected with some moving part of the machine. The pall is made double-headed as shown, and thrown to one or other side of the centre of the wheel according to the direction in which the feed is required—it is steadied in either position by a spring pressing on a flat part of the pall.

The power is communicated to machines by bands and pulleys, or riggers, of which there are always two (and in the case of machines that require to have their motion reversed three), on the machine shaft, one running loose on the shaft, so that while the strap is on that pulley the machine remains at rest. The strap is shifted by a fork embracing it, and when the machine alternates in its motion, this throwing of the strap from one wheel to another is done automatically. Where there are three pulleys the centre one is loose.

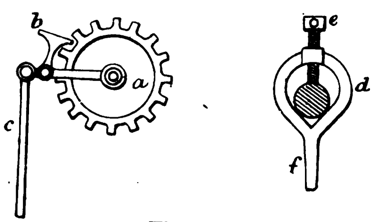
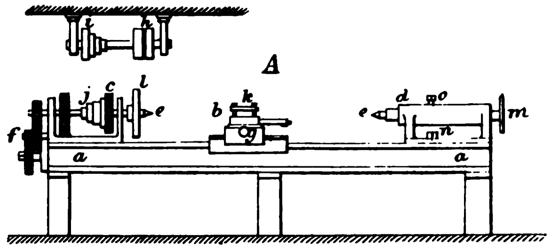
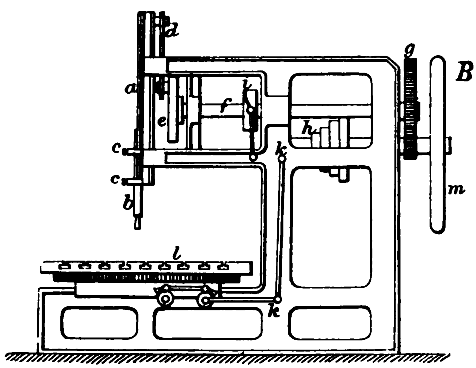


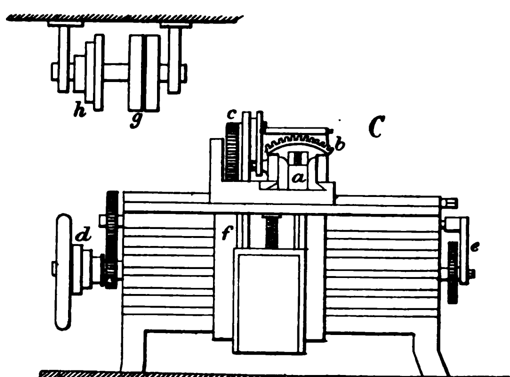
Fig. 27.

In Plates II. and III. are shown the general forms of various machine tools. A is a slide and screw-cutting lathe. *a a* is the lathe-bed, through which runs the "leading screw;" *b* is the slide-rest carrying the tool secured under clamps at *k*; *c* is the headstock, carrying the driving riggers, feed wheels, mandril *e*, and chuck *l*; *d* is the *"poppet head,"* in which is a mandril that can be moved *longitudinally* by a screw actuated by the hand-wheel *m*.

Plate II.







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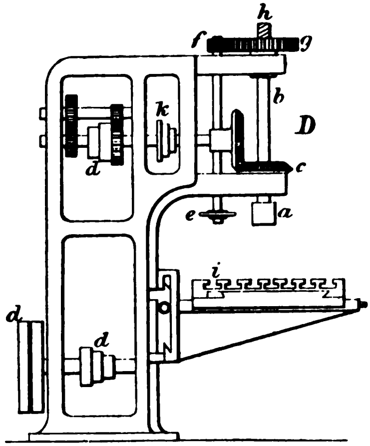
e e are the "centres," upon which the work is carried; at *f* are the toothed or spur wheels by which the feed is regulated, *g* being the transverse feed on the slide-rest; at *h* are the driving and loose pulleys, having on the same shaft the riggers *i*. By the different sizes of the riggers at *i* and *j* the speed is varied, the diameters being so arranged that one band will fit any pair. Of course the greater the diameter of the work, the less must be the number of revolutions per minute. *l* is the face-plate which screws on to the mandrils. The centres *e* have tapered tails fitting into recesses prepared in the mandril and poppet-head to receive them. To chuck, say a bar in the lathe, first the centre at each end is marked by a centre punch, and then a small countersink is drilled to receive the centre *e*. The poppet-head is slid along the lathe-bed so as to make the distance between the centres *e* a little greater than the length of the work to be turned, and there clamped to the lathe-bed by a screw *n*. On one end of the work a "carrier" *d*, Fig. 27, is fixed by a screw *e*; the work being put between the centres, the back one is brought up by the screw and hand-wheel *m*, till the work is held on the centres. The back centre is secured from slipping by the set-screw *o*, and the work is caused to revolve by a stud on the face-plate catching against the carrier-tail *f*, Fig. 27.

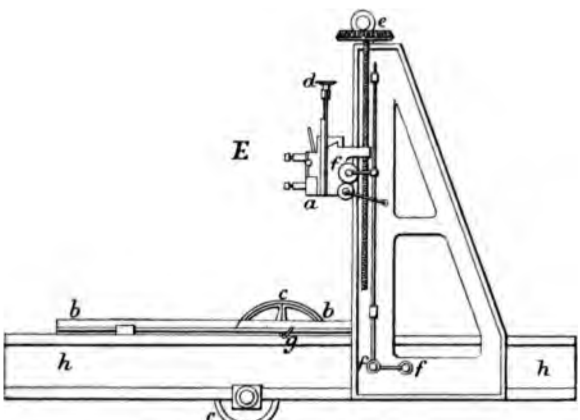
B is a slotting machine—*a* is the vertical bar carrying the slotting tool *b*, secured by the set screws *c c*. The bar is actuated by a link or connecting rod *d*, attached to a crank-plate *e*, fixed on a shaft *f*, at the other end of which spur-wheels connect it with a shaft and driving riggers *h*; on this shaft is a heavy fly-wheel *m*, to accumulate momentum for the "cut;" *i* is a cam driving the feed motion *k k*, by which the table *l* is turned and traversed. C is a shaping machine, front view. *a*, tool-box; *b*, segment and screw to adjust angular position of tool; *d* and *h* speed riggers;

g driving pulleys; *e* feed motion; *f* table or chuck for work. The tool-holder is driven backwards and forwards by a link similar to that of the slotting machine. In both cases the crank-plate is a grooved disc, and the length of stroke is adjusted by the distance of the driving-pin from the centre of the disc. D is a drilling machine. *a* is the drill socket on the shaft *b*, driven by the mitre wheels *c*, from the driving gear *d d d*; *e* is a hand-wheel on a shaft carrying a pinion *f*, which gears into a wheel *g*, the centre of which has a thread cut in it to actuate the screw *h*, by which the drill shaft *h* is raised and lowered; *i* is the table, which can be moved by screws in either direction, and also raised and lowered on vertical slides. E is a side view of a planing machine. *a* is the tool-box, *b b* the planing table, *c c* the driving gear, *d* a hand-wheel and screw for regulating the "cut" of the tool; *e* bevel wheels connecting vertical screws on each side of the machine; *f f* feed gear for moving the tool; *g* a stud which, by knocking a tumbler, shifts the driving band and reverses the motion of the machine; *h h* the bed of the machine. The position of the stud *g* determines the length of travel of the bed. The tool-holder is either made to rock, as shown, to let the work clear in running back for a new cut, or the tool is reversed as well as the machine motion and so cuts both ways; in the former case the machine is geared so as to run back much quicker than forward, in order to save time when the cut is not on.

Punching and shearing machines are generally made with vertical slides, and as the stroke is very short, motion is given by an eccentric working in a rectangular opening in the slide, the width of the aperture being sufficient to allow for the lateral play of the eccentric, and its height equal to the diameter of the eccentric.

Machines called multiple drilling machines are now much used for girder work; they carry a number of drills





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in a row, all driven by one shaft. The feed may be put on the work by small hydraulics under the table.

There are a few multifarious punching machines in England, which up to a certain width will punch any required pattern; these are very complex, and for their description would require more space than is at my disposal in this chapter.

There are also various special machines, such as screwing machines, bolt and nut making machines, &c., &c.

CHAPTER V.

MANIPULATION.

I NOW proceed to the description of the manipulations with which the mechanical engineer must be acquainted in order to complete his work. The fitter will require a tail vice, of the form shown at Fig. 28. It is a large vice with long jaws, one of which is prolonged into a tail, which at its lower end is fixed into a block secured to the floor; at the upper part, just below the screw by which the jaws are tightened up, is an iron lug, by which it is there secured to the bench. The vice should be furnished with pieces of sheet-copper to lay over the jaws and prevent work from being injured by its teeth when necessary; or clams may be used for this purpose, made of an alloy, of 9½ parts lead to one part antimony; sheet-lead alone is also often used.

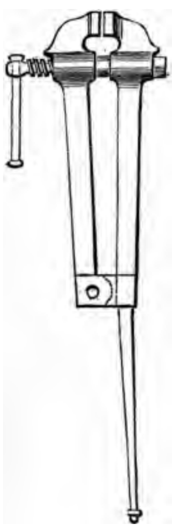


Fig. 28.

When the various castings and forgings come into the shop, with most of them the first treatment will be in the machines.

The round elements, such as shafts, piston and other rods, must be turned in the lathe. In the first place, a rough cut is taken off with the point or side tool, and afterwards a finer cut is taken, producing a smoother surface, which may be finally smoothed—shafts by holding

against them as they revolve very fine emery paper, well oiled; piston rods and articles intended to move longitudinally in packing should be draw-filed, that is, as the work revolves a smooth file is passed along it, but is held at right angles to the length of the work, so that the teeth of the file act sideways, and the work should move very slowly; the object of this is to remove all trace of grooves running round the work, which would tend to tear up the packing besides making excessive friction. From wrought iron the removed parts come away as shavings, and in order to keep it cool, a ley made of soft soap and water drips upon it from a can carried by the rest so as to travel with the cutting tool. I have seen a spiral shaving 32 feet long come off a bar of good iron, without breaking. With cast iron the removed material comes away in chips, so that lubrication of this kind is not required. With screwing machines oil may be used.

Pump plungers of cast iron, after being turned in the ordinary way, should always be draw-filed longitudinally. Some special tools will be mentioned further on in treating of the details of steam-engines.

The SURFACING of work is a tedious process, and one requiring much care and patience for its correct execution. Let us suppose a *flat* surface required, such as that of a steam-valve, which surface is required to move as nearly as possible steam-tight upon another. It is evident that neither by planing, which leaves the surface in minute grooves, or very shallow furrows, according to whether the point or spring tool is used; or filing, which leaves intersecting scratches, can yield so accurate a surface as is required. Scrapers are therefore used. The accuracy of the work is tested as it proceeds, by means of a surface plate or planometer, which is a plate of cast iron strengthened by ribs at the back, so that it will not bend or spring in use. The construction or origination of the surface

plate must be described; but first we must have a straight-edge, hence must commence by making one. Three strips of metal, numbered 1, 2 and 3, are fastened together side by side, and planed as true as possible. Numbers 1 and 2 are then filed and scraped, until when their edges are put together, they fit so accurately that no light can be seen between them; numbers 1 and 3 and 2 and 3 must also be made to coincide; then when any two of the straight-edges taken indiscriminately coincide, they are all perfectly true.

Two surface plates should be made together; they are to be planed with a point tool, and then filed and scraped until, if a straight-edge be laid upon them in any position, light cannot be seen between the surface plate and straight-edge. Red ochre is now rubbed on one of the surface plates, and the other is inverted upon it and moved about: it is evident that the highest point or points of contact of the top plate with the bottom will become marked with the ochre; these parts are then scraped down and the process repeated with both plates, until either of them being rubbed with colour, and the other moved about on it, the whole surface becomes uniformly coloured.

In like manner, having a surface plate, any work to be trued up is applied to it, after it has been rubbed with ochre, and the marked parts scraped down, the process being repeated until a sufficient degree of accuracy has been obtained. The appearance of the scraped surface will be mottled; it is not of course a *mathematical plane*, but it is the nearest approach we can get to it.

By a similar process, cylindrical surfaces may be caused to bear uniformly: thus suppose the bearing of a shaft to be accurately turned, then by rubbing it with ochre and oscillating it in its intended bearings, the first points of contact will be shown, which being scraped down continu-'y, ultimately a uniform surface bearing will be obtained.

For any surface which is intended to move in contact with another, grinding is not to be recommended; as some of the abrading material will most likely imbed itself in the softer parts of the work, and so when the machine is working cause rapid local wear. In some cases, as for the seats of valves dropping on (not sliding into) their seats, grinding in is quite proper, also for cocks that are only turned occasionally on their seats.

The materials ordinarily used for grinding and polishing are, emery, oxide of iron (crocus), oxide of tin, &c., applied by means of a wheel or lap of soft metal, which may be made of lead and antimony in the proportion of nine to one.

Nothing will enable a man to file truly but long practice, the tendency to file round being very great; for as the file is moved backward and forward, the leverage is first on one and then the other side of the work, and the pressure applied by the hands must be varied in accordance, so that the centre of pressure of the two hands is always in the centre of the work: this is very easy to explain, but not easy of execution by the beginner, and when we consider that the final fitting of all the parts of the machines together depend in so great a measure upon the file, we see that the fitter's occupation is one involving considerable responsibility.

In addition to the straight-edge and surface-plate, the mechanic will require other tools, as shown in Fig. 29, for setting out his work. *a* is a pair of common compasses, *b* a pair of outside calipers for taking the diameters and thicknesses of solid bodies, *c* inside calipers for holes, *d* the two combined, useful for undercut work, as when the ends *d* are close on the part to be measured, the thickness can be taken off the ends *e*; *f* is a scriber and block for marking lines, and *g h* an arrangement for finding the centres of round work. By applying the blade g h over the top of

circular piece of work (as, for instance, the end of a crank shaft), so that the two sides of the stock *g* are in contact with the circumference, a line ruled along *g h* will pass through the centre of the circle, then shifting the stock a quarter round and scribing another line across the first, the intersection of the two will be the centre of the circle. Squares of various sizes will also be required.

When holes are required, punching should be avoided as much as possible, as it always injures the plates around the punched holes, and where punched holes are used, the punches should *not be flat* at the ends but of a *spiral* form,

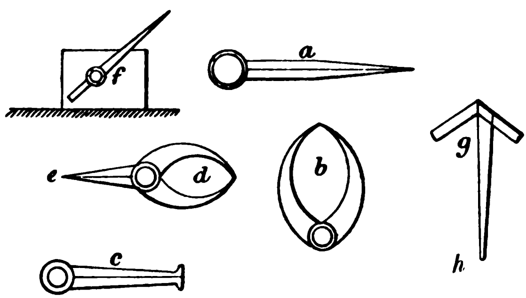


Fig. 29.

so as to exercise more of a shearing action than the bursting-out action of the common punch, and if the latter be used, the holes should be punched $\frac{1}{8}$ inch smaller than finished size and cleared out to the full by a pin drill, which is a drill having its centre prolonged into a pin of the same diameter as the hole to be enlarged.

In boring cylinders intended to be used with pistons working in them, and also in turning large pump plungers and work of a similar nature, the work should not be suspended during the finishing cut; it should be carried right through, for it is obvious that as the cut proceeds the

work will become heated and *expanded;* if then we stop the cut and let it cool, when the cut is again started, the work having contracted, there will be a ridge, very small, no doubt, but *it will be there.*

Steam joints of flanged pipes, cylinder covers, &c., are made tight by enclosing rings of canvas smeared over with a mixture of white and red lead between the metal surfaces. For joints that are to be permanent, iron cement made with iron borings and sulphur may be used, but these, if the cement is properly made, cannot again be reopened without danger of breaking up the work.

In fitting up our shop it is necessary to have some idea of the power that will be required to drive the tools, and although I have not mentioned the engine itself, as that and the boiler will be minutely described further on, I will here give, on the authority of Dr. Hartig's experiments, the power required to drive various machines.

SINGLE-ACTING SHEARING AND PUNCHING MACHINE.— P = horse-power to drive the empty machine; P_c = do. to do the work; t = maximum thickness in inches of plate to be cut; n = number of cuts per minute; a = area of surface cut or punched per hour in square inches; F = (1166 + 1691 b) = the work to shear one square inch.

$$P = 0{\cdot}1 + \frac{n \times t^2}{26{\cdot}7}. \qquad P_c = \frac{a \times F}{1980000}.$$

The total power is of course $P \times P_c$.

PLATE-BENDING MACHINES.—b, t, l, = breadth, thickness, and length of plate in inches; r = radius of curvature in inches; F = net work of bending the plate in foot-lbs.

For cold wrought iron $F = \frac{85000\, b\, t^2\, l}{r}$. For red-hot do., $F = \frac{11300\, b\, t^2\, l}{r}$. The power to drive the empty rolls is 0·5 to 0·6 horse-power.

CIRCULAR SAWS.—d = diameter in inches; n = number of revolutions per minute; then running empty,

$$P = \frac{n\,d}{32000}$$

The net power to cut is proportional to the cubic contents of material removed; a saw for cutting hot iron, moving at a circumferential speed of 7875 feet per minute, and making a cut 0·14 inch wide, the power is, if A equal sectional area of surface cut in square feet, $P_c = 0{\cdot}702$ A, for red-hot iron. $P_c = 1{\cdot}013$ A, for red-hot steel.

ORDINARY CUTTING TOOLS.—W = weight of material removed per hour in pounds; s = average sectional area of shavings in square inches.

Planing cast iron, light cuts,

$$P_c = W\left(\cdot 0155 + \frac{1}{11000 \times s}\right).$$

Average cuts:—Steel, $P_c = 0{\cdot}112$ W; wrought iron, $P_c = 0{\cdot}052$ W; gun-metal, $P_c = 0{\cdot}0127$ W.

The power required for turning metal is less than that absorbed in planing, and greater for small than for larger diameters.

Turning:—Cast iron, $P_c = 0{\cdot}0314$ W; wrought iron, $P_c = 0{\cdot}327$ W; steel, $P_c = 0{\cdot}047$ W.

For *drilling*:—q = cubic inches removed per hour; d = diameter of hole in inches.

Drilling cast iron dry, $P_c = q\left(0{\cdot}0168 + \frac{0{\cdot}0067}{d}\right)$; wrought iron in oil, $P_c = q\left(0{\cdot}0168 + \frac{0{\cdot}0269}{d}\right)$.

Shaping Machine Cuts.—Cast iron, skin cuts, $P_c = 0{\cdot}1087$ W; under-cuts, $P_c = 0{\cdot}0604$ W; notch-cuts (wheel-teeth), $P_c = 0{\cdot}118$ W. The power required to drive the tools *empty* varies for lathes with the number of shafts between

the driving shaft and main spindle; n = revolutions of lathe spindle per minute.

No. of Intermediate Shafts.	Light Lathes.	Heavy Lathes.
0	$P = 0{\cdot}05 + 0{\cdot}0005n$	$P = 0{\cdot}25 + 0{\cdot}0031n$
1 or 2	$P = 0{\cdot}05 + 0{\cdot}0012n$	$P = 0{\cdot}25 + 0{\cdot}053n$
3 or 4	$P = 0{\cdot}05 + 0{\cdot}05n$	$P = 0{\cdot}25 + 0{\cdot}18n$

For drilling machines *empty*: n = revolutions per minute of gear shaft; n_2 = do. of drill.

Drill without intermediate gearing ..	$P = 0{\cdot}0006n + 0{\cdot}0005n^2$
Drill with gearing for spindle	$P = 0{\cdot}0006n + 0{\cdot}001n^2$
Radial drills without gearing	$P = 0{\cdot}0006n + 0{\cdot}004n^2$
Radial drills with gearing	$P = 0{\cdot}04 + 0{\cdot}006n + 0{\cdot}004n^2$

For a slotting machine *empty*. Tool holder and slide weighing 93½ lbs.; n = strokes per minute; s = stroke in inches.

$$P = 0{\cdot}045 + \frac{n \times s}{4000}.$$

For shaping machines moving slowly, the power to move them empty is 10 to 15 per cent. of the gross power absorbed by them.

These quantities must be regarded as rough approximations, for the varying characters of the materials operated on must require constantly varying amounts of power for the execution of the work.

In planing, turning, and boring rough castings, care must be used in taking the *first* cut to let the point of the tool be deep enough to go *under the sand skin*, or its edge will be gone directly. The sand skin should be left on where convenient, as it forms a good protection to the metal beneath, protecting it from corrosion.

All the parts of a machine having been fitted together and to their respective parts of the frame in detail, it now *remains to erect* it, and if the preceding work has been *accurately* executed there will be no difficulty in this. In

the framework of large engines or machinery, when it is built up of different pieces, gauge-points should be marked in line on different parts of the frame, as soon as the whole is accurately erected, in order to show at any future time if any subsidence or straining of the framing has occurred. In marine engines especially is this requisite, where the labouring of the vessel in a heavy sea will put a racking strain, perhaps not only upon her frames, but also on those of the engine; in any case the engines should have a very solid base plate, and the framing be so constructed and self-contained that it shall not bring any strain upon the framing of the ship.

Having now become acquainted with the materials supplied for our use, and the various means by which they may be obtained from the sources found in nature, and also understanding the machinery and processes available for converting these materials to any form that may be required, we are prepared to enter upon the important work of designing and constructing new steam-engines and other kinds of machinery required for the prosecution of our numerous and varied industries.

CHAPTER VI.

PHYSICAL BASIS OF THE STEAM-ENGINE.

IN this chapter I purpose explaining the scientific principles upon which the action of the steam-engine depends, and in so doing I shall avoid any *unnecessary* digression into the paths of pure science, as I am anxious not to introduce theory, beyond what is necessary for the comprehension and proper treatment of the subject now before us.

If we evaporate water steam is formed, and at the ordinary atmospheric pressure will occupy about 1,600 times the space of the water from which it has been formed. If, then, we suppose a cubic inch of water to be enclosed in a tube, and a steam-tight plunger or piston to *rest* upon it, but so that it can move freely in the tube—which we will suppose to be one square inch in area, and open to the atmosphere—then, by applying heat to the tube, the water will be converted into steam; and the piston (which is supposed to be without weight, or counterpoised) is lifted 1,600 inches, pushing out the air before it, and therefore lifting by the elasticity of the steam below about 15 lbs., being the weight of the atmosphere, 1,600 inches, or doing what would scientifically be called 2,400 inch-lbs. of *work*.

Let us pause for a moment to consider what WORK is. If a force of say 10 lbs. is resisted and kept at rest, there being *no motion*, a *pressure*, or *static* force, of 10 lbs. is *exerted; but* if the resistance of 10 lbs. is not merely

balanced, but pushed back through space, *work* is done; if the space through which the resistance is pushed or overcome be, say, 12 feet, the work done is 120 foot-lbs.

In this we have the action of the steam-engine, but as other resistances have to be overcome besides that of the atmosphere the steam is formed in closed vessels (boilers), which, by restricting its volume, causes it to have a greater pressure than that of the atmosphere.

If we take a gas or vapour, and compress it into half its present volume, we shall find we have doubled its pressure per square inch. (It must be understood I am speaking generally, without regard to variations of temperature; for the exact explanation of the matter I would refer such of my readers as desire to study it in detail to the late Mr. Clerk Maxwell's "Text-Book on Heat"); and in like manner if we evaporate 1 cubic inch of water in a vessel having only 800 inches capacity, it will have a pressure of 30 lbs. per square inch instead of 15 lbs. Thus, by evaporating the water in a boiler, we can get the steam of any pressure we desire, the boiler being made strong enough to bear such pressure, and having our reservoir of steam, we can let it out as we want it into the tube with the movable piston, on which its pressure will act to do such work as we require.

Water boiled under atmospheric pressure is at a temperature of 212° Fahrenheit, and the steam formed shows by the thermometer the same temperature; but that steam contains absolutely a great deal more heat than an equal weight of water at the same temperature; this heat which is not shown by the thermometer is called latent heat, and as the sensible temperature of the steam increases with its pressure, so the latent heat diminishes; not, however, *making* the *total heat* constant, as will be seen from the following figures from Regnault's experiments:—At 26 lbs. pressure per square inch, the sensible temperature is 242·3°,

the latent heat 945·6°, the total heat being 1187·9°. Again, at 57 lbs. pressure per square inch the sensible temperature is 289·3°, and the latent heat 912·9°, the total heat being 1202·2°. These pressures are *absolute pressures*, not pressures above the atmosphere. The variations of total heat are not very great, being at 213·1° temperature 1178·9°, and at 381·7° temperature 1220·3°, the pressures being 15 lbs. and 200 lbs. per square inch.

Having thus seen how the power, or rather work, is *communicated* by the steam, it is necessary to inquire from what source that work is obtained.

It has been ascertained and demonstrated by physicists that the various physical forces are correlative, that one can be transformed into another, electricity into heat, heat into electricity, mechanical work into heat, and heat into mechanical work, &c. It is with the relations existing between heat and mechanical work that I now have to deal, for however interesting are the other correlations referred to, they are beside the subject under consideration.

Dr. Joule, by experiments on friction, found that the quantity of heat sufficient to raise 1 lb. of water 1° Fahrenheit, corresponded to an amount of work represented by 1 lb. falling 772 feet, or 772 foot-lbs. of work. This value has been tested in various ways and always verified, and is even so verified by an examination into the difference of the theoretical and actual *velocities of sound* in air.

The quantity of heat required to raise 1 lb. of water 1° Fahrenheit is called one *unit of heat*, and for every unit of heat that *disappears* we have a right, according to the inexorable laws of nature, to expect 772 foot-lbs. of work. In the high-pressure steam-engine, where the steam exhausts into the air, we have no means of ascertaining how much heat is carried away; but in the condensing-engine, *in which the exhaust-steam is again condensed into water, the quantity of* heat left after the work has been done in

the engine may be measured, and the amount of work so done should correspond to the loss of heat experienced by the steam in its passage through the engine. Of course in experiments to determine the quantity of heat disappearing in the steam-engine all losses, by radiation, by contact with air, &c., must be ascertained, and for experiments practically proving the accuracy of the dynamic theory of heat, as applied to the steam-engine, science is indebted to M. Hirn, whose experiments I will now describe—first observing that "working steam expansively" means letting steam into a cylinder only for part of the stroke of the piston, the further motion of the piston being carried on by the expansion of the steam already in the cylinder.

In the steam-engine used in M. Hirn's experiments the steam left the boiler at 146° centigrade, and without loss of temperature entered the cylinder. The temperature of the condenser was 34° centigrade. The steam was worked expansively. The space above the piston was connected with the condenser; and if the expansion were perfect, the vapour underneath the piston at the end of its stroke would be of the pressure due to the temperature of the condenser. Assuming this to be the case, we can, by M. Regnault's experiments, determine the fraction of the total heat which is converted into work; and according to these calculations the heat converted into work in M. Hirn's experiments is something less than $\frac{1}{10}$th of the whole heat. M. Hirn, however, found that $\frac{1}{8}$th the total heat was converted into mechanical effect, and it was subsequently shown that some of the heat was yielded by the condensation of steam in the cylinder; this condensation was demonstrated by M. Hirn. That such a phenomenon should take place was theoretically demonstrated by Mr. *Rankine* and M. Clausius, two of the most energetic supporters of the mechanical theory of heat.

I think this brief explanation of the theory of the action

of the steam-engine will suffice for the purposes of the present work, and shall therefore pass on to the practical designing and construction of these machines; but at the same time I would strongly urge all who really take an earnest interest in the subject to follow up in other treatises the study of the principles of thermo-dynamics, for in few branches of science will be found richer or more fascinating fields of investigation; and in our improved modes of construction may be found the means of realising some of the aspirations of the earlier school of mechanical engineers.

CHAPTER VII.

THE PRINCIPLES OF MECHANICAL CONSTRUCTION.

I WILL now give a brief account of mechanics as applied to the construction of machinery. A machine is interposed between the source of power and the point at which it is expended, its object being to render such force applicable, or to alter the conditions under which it acts. Thus by the steam-engine the elastic force of steam is rendered applicable to the moving of machinery; by levers, pulleys, and other contrivances a *quickly moving* force is changed into a *greater* force moving *proportionately slower*, or *vice versâ*. If 5 lbs. at one end of a bar on a movable centre will balance 20 lbs. at the other end, it will be found that if the bar is caused to move on its centre, while the latter end moves 1 inch the former will move 4 inches; the work balances, in fact; at one end there is 5 lbs. $\times$ 4 inches $=$ 20 inch-lbs., at the other 20 lbs. $\times$ 1 inch $=$ 20 inch-lbs. No force is or can be created or destroyed; the sum total of force in the universe is always the same, existing in two states—"potential" and "active." There is potential work in a piece of coal, which becomes active when it is burned under the boiler of a steam-engine. A consideration of the indestructibility and increatibility of force, the principle of the "conservation of energy," will show the impossibility of perpetual-motion machines, the infatuated search after which has ruined so many ignorant inventors. Those who are brought into contact with this unfortunate class of persons will find that the machine only wants

one little detail altered to get it over the only *hitch* remaining; the little detail required is the supply of power to drive the machine. Of the perpetual-motion machines said to have existed I have only to say they are impudent frauds.

But to resume: I will consider the condition of a force acting about a point as a centre of revolution. The intensity of force, multiplied by the distance of its direction from the centre, is called the MOMENT OF THE FORCE; but this, although expressed as inch-lbs., foot-lbs., &c., must not be confused with the same terms as applied to WORK, or force acting through a certain distance; the former is a static force, or pressure at rest, the latter a dynamic force, or pressure in motion.

Let a bar 6 feet long be fixed on a centre, and at its free end let a force of 10 lbs. act at right angles to its length; the moment of the force about the centre will be 10 lbs. × 6 feet = 60 foot-lbs. Now if the value of a moment be given and one of its terms, the other can be found thus to balance this moment of 60 foot-lbs., suppose there is a *force* of 12 lbs. available; then the distance at which it must act about the centre will be $\frac{60}{12} = 5$ feet, giving the moment 12 lbs. × 5 feet = 60 foot-lbs. In determining a moment, the distance of the centre must be measured at right angles to the *direction of the force*. In Fig. 30 let a force w act in the direction $a\ b$;

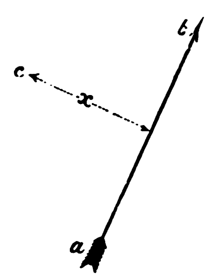


Fig. 30.

it is required to find its moment about the point c; from c let fall a perpendicular upon $a\ b$, and call the length of this perpendicular x; then will the moment of the force about $c = w\,x$. From the above remarks it appears that any two

moments will equal, when the distances of the forces producing them, from the centres to which they are referred, vary inversely as the intensities of the forces. Suppose this condition to be satisfied, and let the moments act about the same centre, but in opposite directions; then will a condition of equilibrium be attained, and in this balance of moments it is that the principle of the LEVER consists.

Take an ordinary bar (neglecting its weight), supported on a pin or gudgeon at one-third of its length, and free to revolve about such pin; if, then, the bar be 9 feet long there will be 6 feet on one side of the pin, or FULCRUM, as it is called, and 3 feet on the other; let a weight of 500 lbs. be attached to the shorter end. It is required to find the weight which, attached to the longer end, will balance it. The weights and their distances from the fulcrum must vary inversely; so by proportion—

$$6 : 3 :: 500 : 250; \text{ because } 500 \times \frac{3}{6} = 250.$$

250 lbs. will, therefore, be the weight required.

This rule will apply to every kind of lever, care being taken to observe the conditions under which it acts. Its principle, however, is the same whether its arms be in the same straight line, or bent at angle to each other. Various forms of levers are shown at Fig. 31, but the same length of arms, and therefore the same conditions of equilibrium, are preserved in each case.

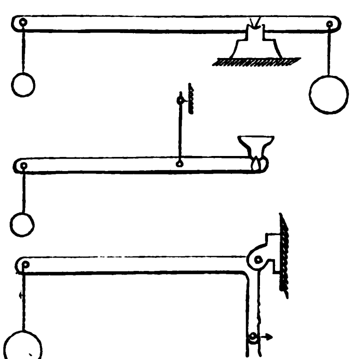


Fig. 31.

The proportions between the weights and arms refer to relative, not to absolute

quantities; thus a lever having arms 3 feet and 6 feet long, will have the same value as one with arms 4 feet and 8 feet long; the proportions being the same in both. I will now examine the work done when the arms move about the fulcrum in the above case. Let the end of the long arm move through 1 foot, then the work will be $250 \times 1 = 250$ foot-lbs.; what then will be the work done at the other end of the lever?

We must first find the space through which the end of the short arm will move, while that of the long arm passes through one foot. The ends of the arms describe circles about the fulcrum, hence in moving through the space mentioned above, part of the circumference of a circle will be described, and the distances passed through will vary as the lengths of the arms which are the radii of the circular arcs; therefore, the end of the short arm that carries the 500 lbs. weight will move through half the distance of the long arm, or through $\frac{1}{2}$ foot, making the work at this end $500 \times \frac{1}{2} = 250$ foot-lbs., which is equal to that performed at the end of the long arm.

It has been stated that a balanced force represents *pressure*, a moving force *work*, and proceeding further and introducing the element of time, POWER is determined.

If $p =$ the force, $d =$ the distance travelled, and $t =$ the time occupied, the power will vary as $\frac{p \times d}{t}$.

From the above observations it will be found that nothing is gained in work or in power by the lever; the amount of work done at the two ends is equal, and it is done in the same time; hence the use of such machines is to enable us to slowly overcome a resistance, which we otherwise could not overcome at all.

The results of the investigation of the principle of the lever may be generalized as follows, in order to apply it to other machines for concentrating power.

In any machine let x = the distance through which a given force is to be exerted, or through which an equivalent weight is to be lifted, and let w = the weight or force. Let y = the distance through which the driving force moves, while w moves through x, and let w' = such driving force. The work executed (neglecting friction) will be $= w\,x$, the work done by the motive power $= w'\,y$; these quantities must be equal, or rather, to produce motion the power must slightly preponderate. The balancing forces will be found from the following equations:—$w\,x = w'\,y$; $w' = w \times \frac{x}{y}$; $w = w' \times \frac{y}{x}$; $x = y \times \frac{w'}{w}$; $y = x \times \frac{w}{w'}$.

These equations will apply to either simple or complex machines, where a uniform resistance is overcome by a uniform force, x being the distance through which the point of resistance moves in a given time, and y the distance through which the point of application of the power moves in the same time.

The PULLEY and AXLE are evidently identical in their action with the two arms of a lever. The INCLINED-PLANE, WEDGE, and SCREW act differently, but the law given above will be applicable, the distances moved through being very easily found; thus when a single-threaded screw revolves once, any body which is being raised by it passes through a distance equal to that between two threads of the screw, measured from centre to centre of thread; this distance is called the *pitch* of the screw.

A very convenient machine for concentrating power is the HYDRAULIC PRESS, the action of which is illustrated by the diagram Fig. 32.

Let a and b represent two cylinders, each having an accurately fitting piston, the lower parts of the cylinders being filled with water, and communicating with each other by a pipe. Let the diameter of a be twice that of b, then because the areæ of circles vary as the squares of

their diameters, the area of the piston in *a* will be four times the area of that in *b*. If we cause the piston in *b* to descend, say, 2 inches, a layer of water 2 inches thick will be displaced from the cylinder *b* and forced into the cylinder *a*, where, however, it will spread out to cover four times the area it did in *b*; hence the layer added to *a* will be only one quarter the thickness of that expelled from *b*, or ½ inch thick, and the piston in *a* will rise through one quarter the distance through which the piston in *b* is depressed; hence a weight on *b* will balance a weight four times as great

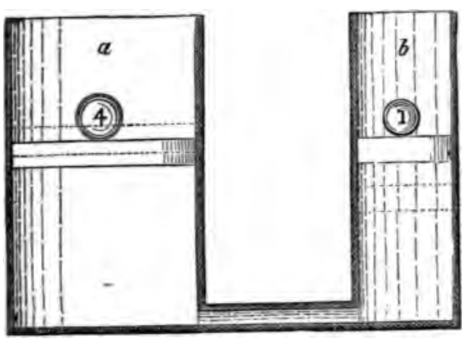


Fig. 32.

placed on the piston at *a*. This may also be shown by another mode of reasoning, based upon the observation that liquids press equally in every direction. Let x be the pressure per square inch on the water in the two cylinders, the water will react in every direction with a force of x lbs. per square inch; but the area of the large piston is four times that of the small one, or contains four times as many square inches, therefore, as the total pressure on each piston is equal to the pressure per square inch multiplied by the *number* of square inches of surface of the piston, *the water will* exercise four times the pressure on the large

piston that it does on the small, or 1 lb. on the small piston will balance 4 lbs. on the large.

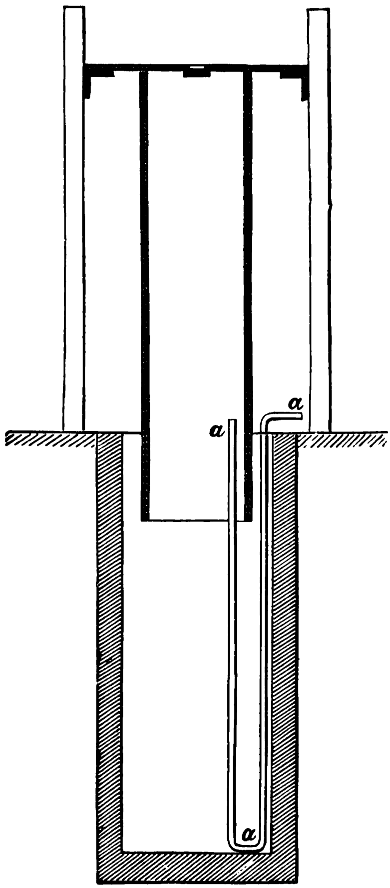


Fig. 33.

The ordinary hydraulic press consists of a cylinder with a piston or ram in it, and a force pump with a small plunger; the force pump is actuated by a lever, so that first the pressure is multiplied by the pump lever, and again by acting on the large surface of the ram. For example, let the pump plunger be $\frac{3}{4}$ inch in diameter, the ram 10 inches diameter, the pump lever 3 inches from the fulcrum on which it turns to the pump plunger, and 33 inches from the fulcrum to the handle, and let the force on the handle be 80 lbs.: what will be the gross pressure on the ram?

Remembering that the lever pressures are inversely as the lengths *of the arms*, and the areæ of the plunger and ram as *the squares of their* diameters, if P be total pressure on

ram; $P = 80 \text{ lbs.} \times \frac{33 \text{ ins.}}{3 \text{ ins.}} \times \frac{(10)^2}{(\cdot 75)^2} = \frac{80 \times 33 \times 100}{3 \times 0\cdot 5625} =$ 156,444 lbs. $= 69\cdot 84$ tons.

There is another method of employing water pressure, by means of a PNEUMATIC LIFT, of which a section is shown at Fig. 33. It consists of a cylinder, closed at the upper end but open at the lower, working in a well as shown. There is a valve in the cover, the use of which will presently appear. The pipe *a*, *a*, *a*, is connected with an air pump, by which air is forced into the cylinder, displacing the water in its upper part, and causing it to stand at a higher level outside than inside the cylinder, this again will cause a greater pressure on the water at the bottom of the well, which acting through the water upwards will press against the air in the lift cylinder, which will thus be raised. By opening the valve at the top the cylinder is sunk.

Assuming that any required air pressure can be got, the limit to this machine in respect to weight raised will depend upon the head of water for which there is room in the well, the head being the difference between inside and outside water levels.

One cubic foot of water weighs 62·5 lbs., therefore a column one foot high and one inch square weighs 0·434 lbs. —if then $d =$ diameter of lift cylinder in inches and $h =$ head of water and $L =$ lifting power; $L = 0\cdot 7854\, d^2 \times 0\cdot 434\, h = 0\cdot 34\, d^2 h$. Let the diameter of the cylinder be 20 inches, then for each foot of water, $L = 0\cdot 34 \times 20 \times 20 = 136$ lbs. By making $d =$ diameter of air pump the pressure necessary to be put upon its piston to give this head is found.

PULLEYS and ROPES give an increase of pressure proportionate to the number of ropes that are simultaneously shortened. If the rope pass over a fixed pulley there is no increase of pressure, only a change in the direction of the *force*; *if, however*, the weight to be lifted is hung on a

pulley carried on a rope of which one end is fixed above, it is evident that in lifting the weight the rope on both sides of the pulley is shortened, so the force is double, and the rope pulled in is twice the length of the distance the weight is raised, and so on.

The TOGGLE, a very powerful machine, is shown at Fig. 34. A C B consists of two arms A C, C B, jointed at C; the end A works on a fixed pin, but at the other end B, a

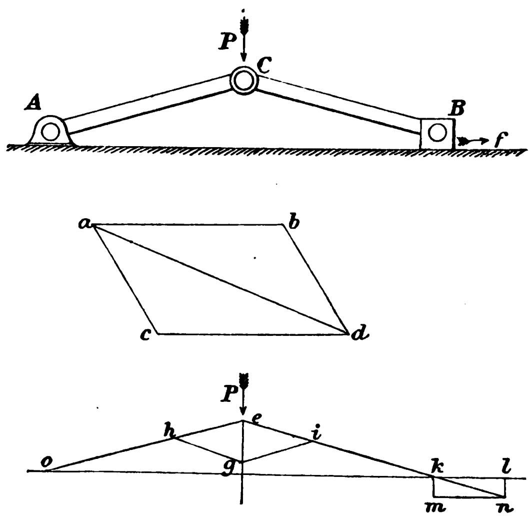


Fig. 34.

block can move on the bed or guide in the direction *f*. The power is applied in the direction of the arrow P.

To determine the increase of pressure for any point (for it increases as the arms straighten, until when they are just straight it is infinite) the principle of the PARALLELOGRAM OF FORCES must be introduced, so I will now explain it. Let *a b* and *a c* be two forces acting at *a*; complete the parallelogram *a b d c*, that is, draw *b d* parallel and equal to

a c, and *c d* to *a b*; and draw the diagonal *a d*. Suppose the force *a b* to act first and drive a body at *a* to *b*, then let *b d*, parallel and equal to *a c*, act next, the body will be driven from *b* to *d* and be in the same position as if it had passed along *a d*, as it will if both forces act together. We can thus resolve two given forces into one, or one into two, *if the directions of the latter be given*. In applying this principle practically, the lines must be drawn to some scale, such as an inch for 100 lbs. or whatever size may be suitable, and of course all the forces must be put down to the same scale. Let *o e*, *e k*, be the arms of the toggle; in the direction of the force P draw $eg = P$, complete the parallelogram *ehgi*, then *e i* will be the pressure along the arm *e k*, at the end of which it acts partly to push the block towards *l* and partly to press it against the guide in the direction *km*; draw in these two directions lines as long as may be required; draw in the direction *e k* continued, the line *kn*, making it equal to *e i*, and complete the parallelogram *k l n m*; then *k l* will be the force with which the block B is urged towards *f*. (A fuller account of the Parallelogram of Forces, and its proof by the principle of moments, is to be found in the Author's Treatise on "Materials and Construction.")

I now have to treat of machines acting by IMPACT, and expending in a short time work which has taken longer to accumulate; such as hammers, and certain punching and shearing machines.

If a body fall freely there will be at any given moment ACCUMULATED WORK in it equal to its weight multiplied by the distance through which it has then fallen unresisted; thus, if a hundredweight fall 15 feet, the accumulated work will then be $112 \times 15 = 1680$ foot-lbs.; here will be force 112 lbs. acting through 15 feet; let this work be expended in driving a pile one inch ($\frac{1}{12}$ foot), the average pressure on the pile will be $\frac{1680}{\frac{1}{12}} = 1680 \times 12 = 20{,}160$ lbs.

Let h = height of fall and w = weight of body, then the accumulated work = $w\,h$. Knowing the laws of falling bodies a formula may be found, giving the accumulated work in any body of which the weight and velocity are known.

Observation shows that a free body under the action of gravity falls 16·1 feet in the first second; it is evident that this being the *mean speed*, as the speed at the commencement is 0, that at the end of the first second must be 32·2 feet, for the average of 32·2 and 0 is 16·1. At the end of the first second the distance fallen is 16·1 feet, velocity acquired 32·2 feet per second; in the second interval of a second the body by its already acquired velocity will pass through 32·2 feet, and gravitation will, still acting, take it through another 16·1 feet and impart another 32·2 feet of velocity. The distance fallen in *two* seconds will be (32·2 + 16·1) + 16·1 = 64·4 feet; velocity acquired 32·2 + 32·2 = 64·4 feet. Following this up it will be found that the velocity varies as the time, and that the height fallen varies as the square of the velocity. Let v = velocity in feet per second; h = fall in feet; t = duration of fall in seconds. 32·2 is usually represented by g in works on Mechanics, representing the force of gravity. (This quantity varies for different parts of the earth; it is 32 feet 1 inch at the equator, 32 feet 2 inches in London, and 32 feet 3 inches at Spitzbergen; but the figures I have taken are sufficient for practical purposes.) From the relations above shown it is found that:—

$$h = \frac{g\,t^2}{2} = \frac{t\,v}{2} = \frac{v^2}{2\,g} : \; v = g\,t = \frac{2\,h}{t} = \sqrt{2\,g\,h} \; :$$

$$t = \frac{v}{g} = \frac{2\,h}{v} = \frac{\sqrt{2\,h}}{g} : \; g = \frac{v}{t} = \frac{v^2}{2\,h} = \frac{2\,h}{t^2}.$$

By substituting other values for g, these equations will hold good for other forces. The formula for accumulated

work may now be transformed, $w\,h = \frac{w\,g\,t^2}{2} = \frac{w\,v^2}{2\,g}$.

$\frac{w}{g}$ is called the MASS of the body, and signifies the quantity of matter contained in it, in regard to its relation to any force acting upon it; let $\frac{w}{g} = m$, then $w\,h = \frac{m\,v^2}{2}$.

Whenever a mass is in motion, if the velocity be known and the mass or the weight, the accumulated work can be determined, *no matter by what force* that velocity has been imparted to it. Let a wheel (such as the fly-wheel of a punching press) weighing 500 lbs., be revolving at such velocity that a point in its rim will travel 4 feet per second, the accumulated work will be: $w\,h = \frac{w\,v^2}{2\,g} = \frac{500 \times 16}{2 \times 32{\cdot}2} =$ 124·2 foot-lbs.

Let a railway train be travelling at 50 miles per hour, its weight being 200 tons. The velocity must be found in feet per second; there are 5,280 feet in a mile; hence $v = 50 \times \frac{5280}{60 \times 60} = 50 \times 1{\cdot}4\dot{6} = 73{\cdot}\dot{3}$ feet per second, and $\frac{w\,v^2}{2\,g} = \frac{200 \times (73{\cdot}3)^2}{2 \times 32{\cdot}2} = 16{,}731$ foot-tons. If this train is stopped by brakes in 800 feet, the retarding effort is equal to a mean force $\frac{16731}{800} = 20{\cdot}91$ tons.

Next will be considered the forces connected with ROTATORY MOTION of bodies. Let us suppose a body to be set in motion in the direction *a b*, Fig. 35; it is evident that in the absence of any other force the body will move in the same direction continually, but a curved motion may be produced by causing a second force to act upon the body in some other direction than *a b*; let the body be attached to one end of a string *a e*, then it will be compelled

to describe a circular arc about the point *e*; let its velocity be such that it will pass from *a* to *d* in one second, then we may call the chord *a d* the velocity of the body, as when the arc is small it will very nearly coincide with its chord. Referring to the diagram, it is evident that the string by its tensile resistance will in one second have drawn the body through the distance *b d*. *b d* is equal to *a c*, *a b d c* being a rectangle. Produce the radius *a e* to meet the circumference of the circle in *f*, and join *f d*, then because the angle *a d f* is inscribed in a semicircle, therefore it is a right angle, and the angle *d a f* is common to the two triangles *a c d*, *a f d*; hence these triangles are similar, the angle *a c d* being a right angle, because *c d* is parallel to *a b*, a tangent to the circle at the point *a*; therefore $\frac{a\,c}{a\,d}=\frac{a\,d}{a\,f}$; but $a\,d = v$, the velocity of the body in feet per second, and if $r =$ radius of the circle, $af = 2\,r$; wherefore $\frac{a\,c}{v} = \frac{v}{2\,r}$, $\therefore a\,c = \frac{v^2}{2\,r}$. From this expression the value of the centrifugal force can now be found by proportion. The weight of a body is the force tending to impart motion towards the centre of the earth; centrifugal force is the reaction of a body compelled to gyrate about a centre, *tending to force it* away from that centre; the measure of *the first force, that* of gravity, is 16·1 feet; the second

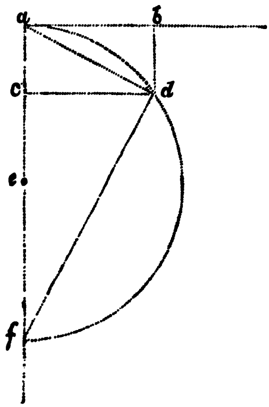


Fig. 35.

$\frac{v^2}{2r}$. Let c = the centrifugal force, and w = weight of the body, then:—

$$16{\cdot}1 : \frac{v^2}{2r} :: w : c. \quad \therefore c = \frac{w v^2}{32{\cdot}2\, r}.$$

The steam-engine and some other machines have attached to them, as a regulator, or as a speed indicator, some form of the conical pendulum; I shall therefore here explain the principle upon which it acts. Let *a b*, Fig. 36, represent a wire or string fixed by a pin at *a* and carrying a heavy ball at *b*; let this ball be revolving in an orbit such as that shown by the circle *b c*, from *a* let fall a perpendicular to the horizon as shown at *a d*, the perpendicular passing through the centre of the circle *b c*, and forming the axis of the imaginary cone *a b c*, described by the revolution of the arm *a b*. From the centre of the ball *b* draw *b e* perpendicular to *a d*, complete the parallelogram *a e b f*, there will be two forces acting on the ball *b* tending to move it about *a* as a centre. The weight being *w* it will produce a force whose moment about $a = w \times e\,b$, and if c = the centrifugal force of the ball the outward moment $= c \times e\,a$; if the ball is in equilibrium these two forces *must balance*, and $c \times e\,a = w \times e\,b$. Let $h = e\,a$, the

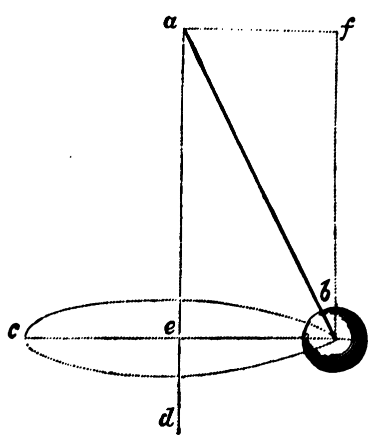


Fig. 36.

height of the point of suspension above the plane of gyration; r = radius of gyration $e\,b$, then $c = \frac{w\,v^2}{32{\cdot}2\,r}$.

Let n = the number of revolutions per minute, $v^2 = \left(\frac{3{\cdot}1416\,r \times 2\,n}{60}\right)^2$; $h = e\,a = \frac{w \times e\,b}{c} = \frac{w \times r}{c} = \frac{w \times r}{\frac{w \times v^2}{r \times 32{\cdot}2}} =$

$\frac{32{\cdot}2 \times r^2}{v^2} = 32{\cdot}2 \times r^2 \times \left(\frac{60}{3{\cdot}1416\,r \times 2\,n}\right)^2 = \frac{2936{\cdot}5}{n^2}$ feet,

which $= \frac{2936{\cdot}5 \times 12}{n^2} = \frac{35235}{n^2}$ inches $= \left(\frac{187{\cdot}7}{n}\right)^2$, and by transposing, $n = \frac{187{\cdot}7}{\sqrt{h}}$.

CHAPTER VIII.

GENERAL ARRANGEMENT OF STEAM-ENGINES.

THE power of the engine comes first for consideration. This can only be calculated approximately in the first case, although, after the engine is made, it can be accurately ascertained. The steam pressure is first converted into mechanical power by causing it to propel a steam-tight piston in a cylinder. The amount of work done in a given time will be equal to the effective pressure per square inch on the piston, multiplied by the area in square inches of the piston, and by the distance passed through by the piston; for example, let d = diameter in inches = 35; effective pressure of steam p = 80 lbs. per square inch, and v = velocity of piston in feet per minute = 400. Then area of piston = $\cdot 7854\, d^2$ = 962 square inches, dropping decimals, and the work done in one minute $= p \times v \times \cdot 7854\, d^2 = 80 \times 400 \times 962 = 30{,}784{,}000$ foot-lbs. per minute. The work which a horse is capable of doing is taken at 33,000 foot-lbs. per minute, hence if HP = the HORSE-POWER, then in this case $\text{H P} = \dfrac{30784000}{33000}$ = 933 horse-power nearly.

The measurements requisite for determining the horse-power are easily ascertained, except the effective pressure of steam, which must be estimated according to the best means at our disposal *before* the engine is made; *afterwards* it can be accurately ascertained, as will be shown further on.

There are certain rules for what is called NOMINAL horse-power, of no practical use, but commercially used in buying engines, which refer to the size of the engine and an assumed velocity and pressure; this power varies from one-half to one-eighth of the actual power of the engines. If N H P = nominal horse-power, then by the "Admiralty Rule," $N\,H\,P = \frac{d^2 v}{6000}$. Mr. Bourne's rule for land and paddle engines, if s = stroke of piston in feet, is $NHP = \frac{d^2 \sqrt[3]{s}}{47}$, and for screw engines $N\,H\,P = \frac{d^2 \sqrt[3]{s}}{23{\cdot}5}$.

Having disposed of these empirical rules, I will now consider the question of effective pressure.

The EFFECTIVE PRESSURE at any moment on the piston is the difference between the pressures on the two sides of the piston; hence it is not only the boiler pressure to be considered, but that at the back of the piston. Steam pressure is spoken of in two ways, *absolute pressure* and *pressure above the atmosphere*, the latter being meant when steam pressure is simply used, as that is the pressure indicated by the gauges and safety-valves; when "absolute pressure" is meant it is specially stated so. The difference between the two is generally taken as 15 lbs. per square inch, which, though not absolutely accurate in a scientific sense, as the pressure of the atmosphere varies, is sufficiently near for all practical purposes.

There are two distinct classes, to one of which every steam-engine is referable, CONDENSING ENGINES and NON-CONDENSING ENGINES; in the first the steam, after doing its work in the cylinder, passes into a vessel called the condenser, where it is condensed again into water, and in which a more or less perfect vacuum is maintained. What the pressure in this vessel lacks of atmospheric pressure, is called the amount of vacuum; thus for instance, if, when

the atmospheric pressure is 14·7 lbs. per square inch, the absolute pressure in the condenser is 3 lbs., we should have 14·7 — 3 = 11·7 lbs. of vacuum. In the non-condensing engine the steam leaving the cylinder escapes into the air.

The steam pressure in the cylinder must be less than that in the boiler, loss arising from friction in the pipes and sometimes from cooling on the way. The pressure at the commencement of the stroke of the piston in the cylinder is called the INITIAL PRESSURE, and an average of all the pressures at every point of the stroke is called the MEAN PRESSURE. In condensing engines, for the effective pressure there must be added to the mean pressure the mean vacuum; and for non-condensing engines, from the mean pressure must be deducted the mean BACK PRESSURE, being that due to the resistance of the escaping steam.

The steam may be used by working it at the full pressure throughout the stroke, or by cutting off the supply at a certain part, and letting the remainder of the stroke be made by the expansion of the steam already in the cylinder. The law of a perfect gas is, at a constant temperature, that the volumes vary inversely as the pressures; now steam is not a perfect gas, nor is the temperature absolutely constant in the steam-engine, but with the working margin that exists, it is near enough for practical purposes to regard it as a perfect gas in determining the size of an engine for any required power; in applying this mode of calculation the *total or absolute pressure* must be taken. If steam at 60 lbs. be expanded to twice its volume, this would give 30 lbs. at the end of such expansion, but reference to a table of volumes and pressures will show that the pressure when the volume is doubled is about 28 lbs.

Let us suppose the stroke to be divided into 20 equal parts, and steam let in at the initial pressure for the first

half or 10 parts; then for the end of each following 10th part, if the initial pressure be 60 lbs., the pressures shown by the rough approximation given above are shown in column A in the following table, and those found from a table of volumes and pressures are given in column B.

		A lbs. per sq. in.	B lbs. per sq. in.
At $\frac{11}{20}$ of the stroke-pressure	$= 60 \times \frac{10}{11} =$	54·5	54·3
$\frac{12}{20}$,, ,,	$= 60 \times \frac{10}{12} =$	50·0	50·0
$\frac{13}{20}$,, ,,	$= 60 \times \frac{10}{13} =$	46·1	45·0
$\frac{14}{20}$,, ,,	$= 60 \times \frac{10}{14} =$	42·9	41·5
$\frac{15}{20}$,, ,,	$= 60 \times \frac{10}{15} =$	40·0	38·4
$\frac{16}{20}$,, ,,	$= 60 \times \frac{10}{16} =$	37·5	35·9
$\frac{17}{20}$,, ,,	$= 60 \times \frac{10}{17} =$	35·3	33·6
$\frac{18}{20}$,, ,,	$= 60 \times \frac{10}{18} =$	33·3	31·6
$\frac{19}{20}$,, ,,	$= 60 \times \frac{10}{19} =$	31·6	29·8
$\frac{20}{20}$,, ,,	$= 60 \times \frac{10}{20} =$	30·0	28·1
		10)401·2	10)388·2
Average		40·12	38·82

Taking the least, the average pressure is 38·82 lbs. absolute per square inch for the second half of the stroke, the pressure for the first half is 60 lbs., hence average for the whole stroke $\frac{60 + 38{\cdot}82}{2} = 49{\cdot}41$ lbs.; deducting atmospheric pressure, there is left $49{\cdot}41 - 15 = 34{\cdot}41$ lbs. per square inch mean pressure above the atmosphere. To this is to be added the vacuum, or from it deducted the back pressure, as the case may be, for the MEAN EFFECTIVE PRESSURE per square inch of piston.

The advantages of working steam expansively are very obvious; for instance, in the example taken all the work done in the second half of the stroke is a gain upon what would be obtained if the steam were worked *solid* throughout.

I have shown above that the general expression for *horse-power is:—*

$$\text{HP} = \frac{p \times v \times 0{\cdot}7854\, d^2}{33000} = \frac{p \times v \times d^2}{42000} =$$

$$0{\cdot}000024\, p\, v\, d^2 \text{ (nearly).}$$

From which by transposition the following formulæ are obtained:

$$p = \frac{42000 \times \text{HP}}{v \times d^2}; \; v = \frac{42000 \times \text{HP}}{p \times d^2};$$

$$d = \sqrt{\frac{42000 \times \text{HP}}{p \times v}}.$$

Assume the engine to be non-condensing and to have a back pressure of $2\frac{1}{2}$ lbs. per square inch, and the mean boiler pressure above the atmosphere, 34·41 lbs. per square inch. Let the velocity of the piston be 200 feet per minute and the gross horse-power required 60. Then $p = 34{\cdot}41 - 2{\cdot}5 = 31{\cdot}91$ lbs., and

$$d = \sqrt{\frac{42000 \times 60}{31{\cdot}91 \times 200}} = \sqrt{413} = 20{\cdot}32 \doteq 20\tfrac{3}{8} \text{ in. (nearly).}$$

If space does not prevent it the stroke should be made about twice the diameter, then it will be, say, 3·5 feet, and as there are two strokes for each revolution of the main shaft the number of revolutions per minute will be, if s = stroke in feet, and n = number of revolutions per minute:—

$$n = \frac{v}{2\,s} = \frac{200}{2 \times 3{\cdot}5} = 28{\cdot}57.$$

It will be seen, that so long as the parts of the engine are made strong enough the power depends upon the supply and pressure of steam, so that the boiler becomes the *real* measure of the horse-power available, but the engine must of course be designed for the maximum horse-power at which it may be worked. The power of an existing engine is determined by means of an instrument *called an* INDICATOR. This, in its common form, consists

of a small cylinder, which may be attached to either end of the working cylinder by suitable connections, and contains a piston fitting accurately, but without packing, so that its motion may be as nearly without friction as possible. The indicator piston is held in position when at rest by a spiral spring, carefully made so as to compress or extend through equal distances for equal additions of pressure. When this instrument is in communication with the steam cylinder, its piston will rise and fall with variations of steam pressure, or of vacuum, and a pencil being carried by its piston-rod will mark these variations on a piece of paper against which it is held by a spring. The paper on which the INDICATOR DIAGRAM is to be drawn is attached to a barrel, which revolves to and fro by means of a cord wrapped in a groove at the bottom of the barrel, and having its free end attached to some part of the engine, which will give the proper amount of movement or travel to the paper; the return motion of the paper is obtained by a spring within the barrel. These indicators must be very carefully made and accurately adjusted, and even then they are not all that can be desired. There must be *some friction* with the piston, and if the steam be dirty and carries dirt into the indicator cylinder, serious interference with its action must ensue. The piston and rod in reciprocating acquire some momentum, which tends to carry the pencil beyond the point corresponding to the pressure, and so give a jerky line. This has been reduced in Richards's Indicator, where the piston has a very short stroke, the necessary length of travel being given to the pencil by a suitable lever arrangement; this is a great improvement upon the old-fashioned indicators, but still it retains the piston.

There has, however, been recently invented a very ingenious form of indicator in which the piston and spiral spring are dispensed with, it is known as KENYON'S PIS-

TONLESS INDICATOR, the principle of which I will now explain.

If steam under pressure be admitted into a closed curved tube, it will tend to decrease the curvature of the tube, as by straightening it the capacity is increased; such straightening is resisted by the elasticity of the material of which the curved tube is made, and the amount of alteration of shape will thus correspond to the pressure of the steam within the tube. By the action of such a curved tube the pencil is moved in the indicator under consideration; it is shown in elevation at Fig. 37. *a* is the connection for attachment to the main cylinder of the steam-engine, *b c* the curved tube of which one end is in communication with the cylinder and the other is closed. At the closed end *c* is a link *c d* attached at *d* to a lever *e f*,

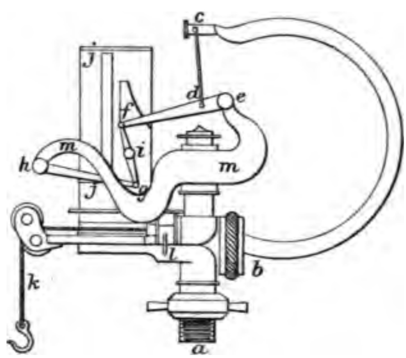


Fig. 37.

which lever moves about a fixed centre at *e*; the other end *f* is jointed to the upper end of a link *f g*, of which the lower end *g* is jointed to the link *g h*, moving upon a fixed centre at *h*. At *i* is the pencil which marks the diagram on a paper carried on the drum *j j*. The position *i* is so chosen that although the points *f* and *g* move in circular arcs, the point *i* moves in a straight line. This arrangement is called a parallel motion, the principle of which will be described further on. *k* is a cord wrapped round *the pulley at* the bottom of the barrel j j (the barrel can be

disengaged from this pulley by the handle *l*), and carried to some moving part of the engine. *m m* is the frame upon which the parallel motion is mounted. At the first glance we cannot fail to be struck with the extreme elegance of this instrument, and indeed it seems replete with the elements of perfection; the only friction about it is in the joints of the motion, there being no piston there can be no sticking or jumping, and although the curved tube must be very carefully made and adjusted, the apparatus is supplied at a very moderate cost.

In Fig. 38 I show three diagrams (reduced to half-size) taken by Kenyon's Indicator. A refers to a Corliss Mill engine; B and C are from the high and low pressure cylinders of a compound marine engine. In each diagram *a a* is the atmosphere line. Now taking diagram A we find at the point *g* a steam pressure represented to scale by the line *e*, and below a vacuum represented by the line *f*. Let us follow the course of the line traced by the indicator beginning at *b*; the steam entering the *top* of the cylinder of the steam-engine (by its action in the tube *b c* of the indicator) drives the indicator pencil up to *c*; as the piston of the engine moves this pressure falls to the point *d*, where the steam is cut off, the remainder of the stroke being made by the expansion of the steam already in the cylinder. The falling of pressure from *c* to *d* appears to be due to insufficient area in the steam passages, for the initial pressure should be indicated up to the point of cutting off the steam. From *d* the pressure sinks, crossing the atmosphere line down to *h*; then the exhaust valve is opened and the piston having finished its stroke commences its return; the *boiler pressure* being now on the other side of the piston, when the piston on this return stroke has reached a point corresponding to *g*, the exhaust valve is closed and the pressure rises, by the compression of the vapour left in the steam cylinder. It will from this be

seen that the work indicated by that part of the diagram below the atmosphere line really belongs to the *up steam* stroke, but assuming the action of the steam to be the same at both ends of the cylinder, we may add this action

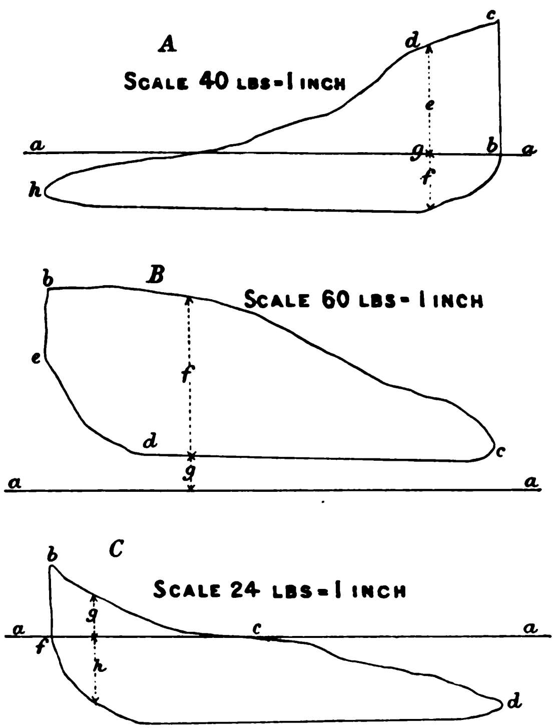


Fig. 38.

to the upper part of the diagram, and in fact if we have diagrams of both ends of the cylinder and treat them both alike, what we take from one is given to the other, hence in practice the ordinate $e + f$ is taken for the *effective pressure* corresponding to the point g.

To find then the mean steam pressure, the mean of all such ordinates as $e + f$ must be taken: this is found by drawing vertical lines at equal distances through the diagram and taking the mean of their lengths, or *more accurately* by determining the area of the diagram and dividing it by the length, then the mean pressure is found. Thus in fortieths of an inch the area of the figure $c\,d\,h\,b$ is 1782; its length is 96, and $\frac{1782}{96} = 18{\cdot}5$ lbs. per square inch.

In using very high degrees of expansion, it is evident that there will be a great variation in the force acting on the piston during the stroke, and this may be in some measure reduced by working with two or more cylinders of different sizes. In this arrangement the high-pressure steam first enters the smaller cylinder, and having done its work there *expands* into a cylinder of larger diameter; here the back-pressure in the high-pressure cylinder is equal to the steam pressure in the low-pressure cylinder. The steam passages between the cylinders must be made as short as possible, so that the steam shall not *uselessly* expand much in passing from one cylinder to the other. These are called COMPOUND ENGINES.

The action of the steam in such an engine is shown in diagrams B and C, Fig. 38.

In the diagram B it will be noticed the pressure does not fall to that of the atmosphere; there is a *back-pressure*, g, which corresponds to the initial-pressure, $f\,b$, in the low-pressure cylinder, in which the greater part of the energy is obtained by the vacuum.

The diagrams B and C were taken from the engines of a steamship making 80 revolutions per minute; the steam pressure being 70 lbs. per square inch, vacuum 25 inches of mercury, or 12¼ lbs. per square inch. The mean effective pressure from diagram B is 36·2 lbs. per square inch; that from diagram C 8·7 lbs. per square inch.

From what I have here explained it will be seen that from an indicator diagram (taken by a *reliable* instrument), not only can the actual power of the engine be determined, but if there is any defect its position is shown.

Engines have also been made in which the piston rotates about a centre instead of moving in a straight line, the idea being to get rid of the loss of energy due to the reciprocating movements, for of course the momentum in the moving parts must be destroyed and renewed at every change of direction. These engines have not proved practical successes, but I will here give a formula for determining their power. Let r = distance in inches from centre of revolution to nearest edge of piston; R = ditto to farthest edge of piston; b = breadth of piston in inches; p = effective pressure of steam; and n = number of revolutions per minute:—

Area of piston in inches $= b\,(R - r)$; and mean space passed through by piston in one revolution $= \dfrac{3{\cdot}1416\,(R + r)}{12}$ feet $= 0{\cdot}2618\,(R + r)$ feet.

Then $HP = b\,(R - r) \times 0{\cdot}2618\,(R + r) \times \dfrac{n\,p}{33000} = \dfrac{n\,p\,b}{126050}\,(R^2 - r^2)$.

Having considered how to proportion the size of the cylinder to the power required, I will now describe the methods of transmitting such power from the part on which it acts immediately to the point at which it is to be expended.

Fig. 39 is a vertical section of an ordinary steam cylinder with its contained piston and piston-rod. A B C D is the steam cylinder made with covers at the top and bottom, the top cover having an opening in it through which the piston-rod f passes steam-tight; this rod is rigidly fixed to the piston e, which moves steam-tight in the cylinder.

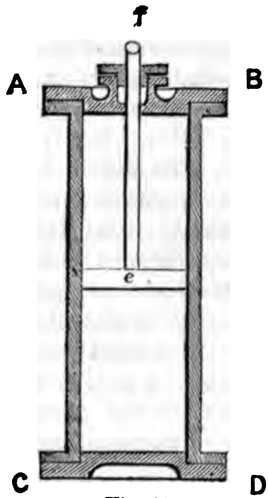


Fig. 39.

The piston-rod is surrounded by greased hemp or other packing, tightly pressed in the box on the cylinder cover, and the piston is packed in a manner to be described further on.

In the first place let the point of application of the power be required to move in a straight line, then the piston-rod may act directly upon the work, or it may operate through the intervention of a beam; but if this latter arrangement is employed some means must be taken to enable the head of the piston-rod to move in a straight line, although the end of the beam moves in a circular arc,

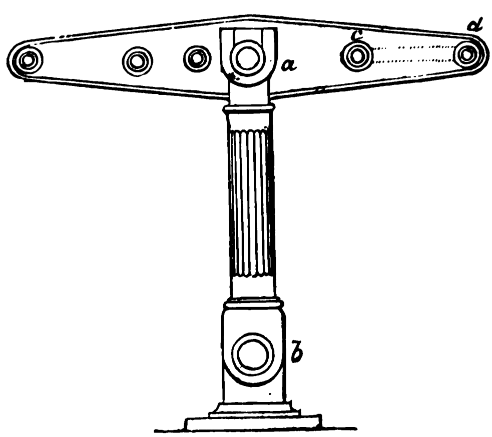


Fig. 40.

for otherwise the piston-rod would be bent at the first

stroke. The means of effecting the desired end are very numerous, but I shall here only describe some of those that have been found practically efficient. The simplest method consists in so forming the column *a b*, Fig. 40, which supports the bearings upon which the main beam oscillates, that it may vibrate upon an axis placed at *b*, the lower extremity, whereby that end of the beam to which the piston-rod is attached is allowed to adjust itself. The extremity of the beam is caused to move in a practically straight line by the link *c d*, which works on a pin *c*, on the beam, and on another in the fixed framing at *d* in the same vertical plane with the piston-rod. The action of this contrivance is illustrated in Fig. 41. The full lines represent the bars of the PARALLEL MOTION, as it is called, at mid-stroke, when they will be parallel to each other; the dotted lines will show their position when the stroke has been continued, in one direction or other, for a short distance.

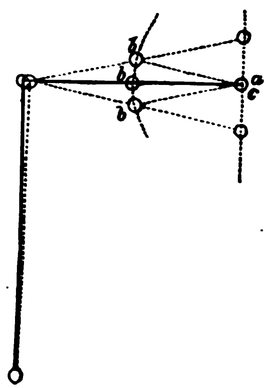


Fig. 41.

The head of the piston-rod is attached to the rod *a b*, &c., at *a*; this bar is at *b* jointed to *b c*, working on the fixed pin at *c*; it will be seen that by as much as the point *a* would be moved to the left by the vibration of *a b* the point *b* is brought to the right by the vibration of *b c*, and thus an almost perfectly rectilineal motion of *a* is obtained.

The foregoing arrangement is only suitable to light and slow-moving machines, as in heavy machinery the oscillation of the beam and rocking-post will give rise to too

much vibration. Fig. 42 illustrates another form of parallel motion, commonly used for beam-engines, which combines in itself the properties of two parallel motions; the first, which is identical in its action with that described

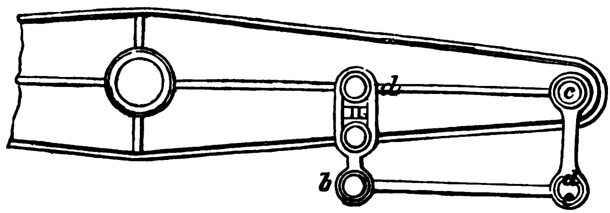


Fig. 42.

above, corrects the deviation of the top of the piston-rod. It is formed by the bars *a b*, *b e* (one is behind the other in the Fig.), of which *a b* is attached to the main beam by the parallel links *a c*, *b d*. At some point in the link *b d*,

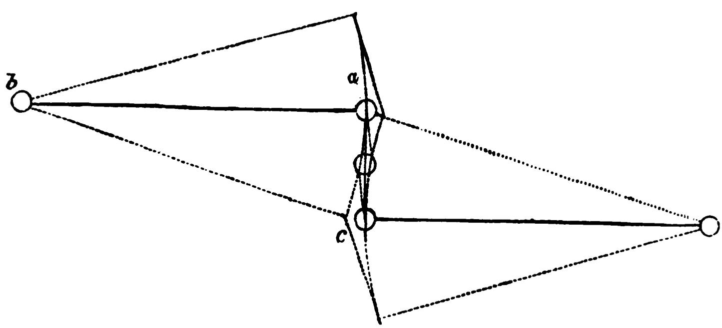


Fig. 43.

depending for its position on the ratio of the length *a b* to the distance from *d* to the centre on oscillation of the beam, its movement will also be rectilineal, as is more clearly illustrated by the diagram, Fig. 43. *a b* is one-half of the

main beam, working upon a fixed centre at *b*; *c d* is a link of equal length, working upon a fixed centre at *d*; the extremities of the two bars are connected by the link *a c*, the whole being so adjusted that at mid-stroke the angles *b a c*, *d c a*, are right angles; then by the oscillations of the arms *a b* and *c d*, the extremities of the link *a c* are caused to deviate in opposite directions. The dotted lines show the paths of various points in the motion; and as a point in the centre of the link *a c* is approached this motion becomes more nearly rectilineal. If the arms *a b*, *c d*, be not of equal length, it is evident the point of rectilineal motion will not be at the *centre* of *a c*, but nearer the longer arm. A motion with unequal arms is shown in Fig. 44, the dotted lines representing, as before, the paths

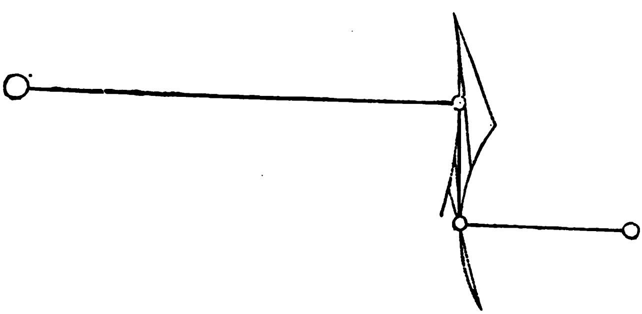


Fig. 44.

of various points in the motion. In American practice it has been customary to use the link *a c*, Fig. 42, and regulate the motion of the top of the piston-rod by guides. This is cheap and accurate, but unsightly and inelegant.

It most frequently happens that the motion of machinery to be driven by steam-power is rotatory, when it will be *necessary to adopt* some contrivance to convert the recipro-

cating rectilineal motion of the piston into a rotatory motion.

There are various ways of attaining this end, but putting aside exceptional cases it is always effected by the use of the crank, the action of which I will now explain.

In Fig. 45 let *a* represent the head of the piston-rod, which is guided so that it can only move in the direction of the straight line *a b*. Let *b c* be a crank capable of revolving about the point *b* as a centre, the extremity *c* describing the circle *c e f g*. The end of the piston-rod is connected with the end *c* of the crank by a connecting-rod

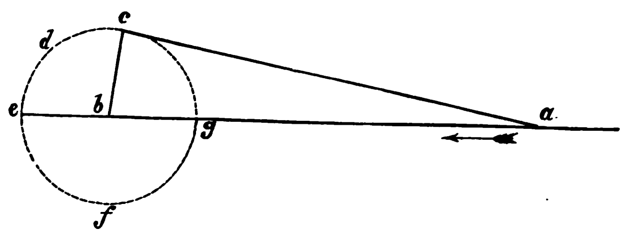


Fig. 45.

a c, the joints *a* and *c* being made by pins, about which the connecting-rod can move freely. If the point *a* be supposed to move forward in the direction of the arrow, the end *c* of the crank will describe an arc from *c* towards *d*, until it arrives at the point *e*, which is in a straight line with *a b*. Then it is evident that in whichever direction the piston-rod head at *e* tends to move, no motion can be produced in *c*, as the force will act at right angles to the direction in which *c* can move. If *c* be carried past this point, and a motion the reverse of the former be imparted to *a*, the end *c* of the crank will pass through the semi-circumference *e f g*; and upon arriving at the point *g* we find that this, like *e*, is a point of no motion. The means

used in practice to carry the crank past these points of no motion, technically called dead points, will be explained subsequently, and I shall at present confine my remarks to the action of the crank in varying the moment of the force acting about its centre.

In Fig. 46 *a* is the head of the piston-rod, *b* the centre upon which the crank revolves, and *c* and *d* the dead points. *a d* is the connecting-rod; the position when the crank is upon the dead point *d* is shown by the full lines.

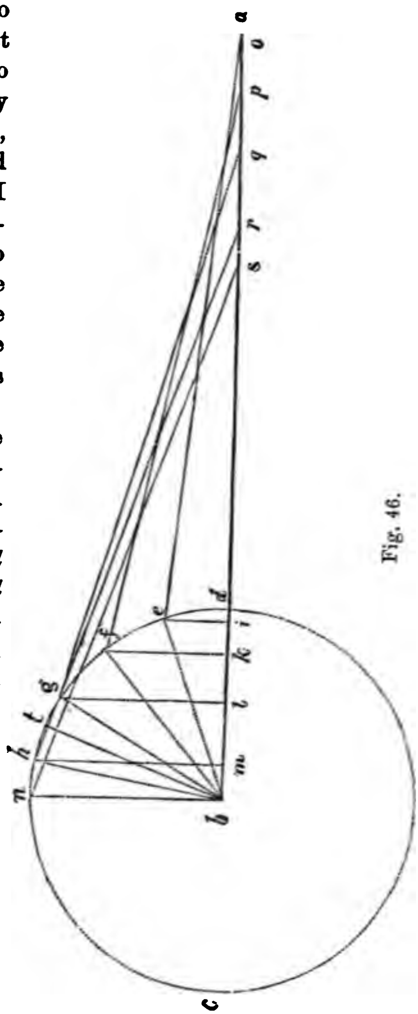


Fig. 46.

The circle, which represents the path of the end *d* of the crank *b d*, is divided into eighteen parts in order that the variation of the moment of force transmitted to the shaft, upon which the crank is fixed, may

be examined at different parts of the stroke. I shall now examine the case for the points e, f, g, h, in the first quadrant of the circle, but include the position $n\,b$, showing the position of the crank when at right angles to the straight line $a\,b$. The static force in each position of the connecting-rod is determined by the principle of the parallelogram of forces.

The length of the connecting-rod being constant, the position of the head of the piston-rod corresponding to each of the points e, f, g, &c., is found by marking off from those points, upon the line $a\,b$, distances $e\,o$, $f\,p$, &c., each equal to the length of the connecting-rod. The first step consists in the resolution of the strain in the directions of the axis of the piston-rod and a line at right angles to the guide, on which the piston-rod head moves. It may be thus concluded that for any position, such, for instance, as that corresponding to the point g, the relative values of the forces will be represented by the sides of a right-angled triangle, formed by the length and position of the connecting-rod $g\,q$, the perpendicular let fall from the point g upon $a\,b$, in this case $g\,l$, and that part of the line $a\,b$ which is contained between the end of the connecting-rod and the perpendicular $g\,l$.

Let P represent the total pressure on the piston, and therefore the force acting in the direction $a\,b$, then the resolution of this force will be as follows:—

The pressure on the guide blocks

$$= \mathrm{P} \times \frac{l\,g}{l\,q}.$$

That on the connecting-rod will be

$$= \mathrm{P} \times \frac{q\,g}{l\,q}.$$

But $q\,g$ is constant; let it $=$ L, then the force upon the *connecting-rod*

$$= \frac{\mathrm{P\,L}}{l\,q}.$$

In order to find the moment of this force about the centre *b*, produce the line *q g*, and from the point *b* let fall upon it the perpendicular *b t*; then will *b t* represent the distance at which the force acts, and the moment about *b* will be—

$$= \frac{\text{P L}}{l\,b} \times b\,t.$$

In a similar manner the moment of force may be found for other positions.

The lower quadrant, immediately beneath *b d*, will exhibit the same phases, the remaining two quadrants being different. Having found a method of calculating the moment, it will be instructive to draw the curve described by the point *t*.

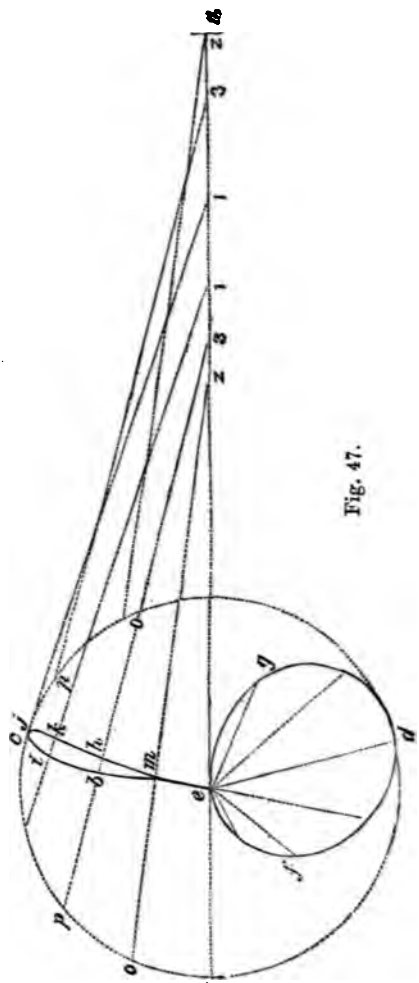


Fig. 47.

Let a b, *Fig.* 47, be the straight line in which the hea

of the piston-rod moves. The change of force due to the position of the crank must first be determined, that on the connecting-rod being for the present supposed to be constant; then the point upon which the perpendicular to the connecting-rod falls will, at each point of intersection, there being fourteen intersections, pass through the points *l, i, j, k, h, m,* and *e*; and if the lengths of these perpendiculars be laid off radially from the centre *e*, along the axis of the crank, for each position we obtain the figure *e f g d*.

The force on the *connecting-rod* is not, however, constant, but varies as its length divided by the horizontal distance between its extremities.

The relative value of the moment actually acting upon the centre *e*, for any position of the crank, may be found, when the pressure in the direction *a b* is constant, by multiplying the length of the perpendicular by the relative pressure on the connecting-rod, the result being represented geometrically by a rectangular or triangular surface. At Z, Fig. 48, is shown an enlarged view of the figure *e f g d*, in which the moments are represented by rectangles. If triangles be taken instead and placed with their apices meeting at *e*, the total sum for every position of the crank in the semicircle may be represented by a solid figure, such as that shown at Z′. If a longer connecting-rod be used, the perpendiculars for all positions in the semicircle nearest the piston-rod will be shortened, those on the opposite semicircle being lengthened, and the figure *e f g d* will more nearly approach a symmetrical form. Therefore the longer the connecting-rod the more uniformly will the engine work.

In the oscillating engine no connecting-rod is used, the cylinder being carried upon trunnions in bearings upon which it can rock, to adapt the position of the piston-rod to that of the crank. In this case there is no correction to be made for the varying angle of the connecting-rod, so the

varying lengths of the perpendiculars only have to be con-

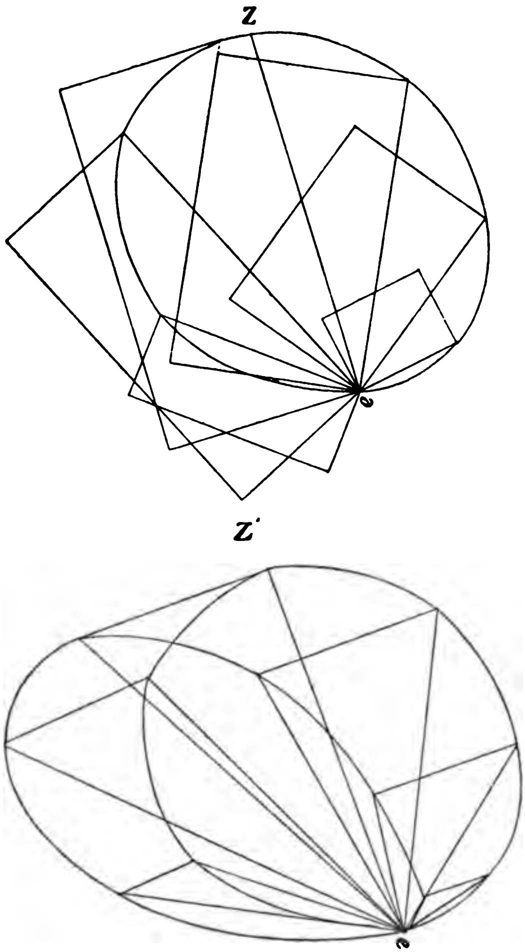


Fig. 48.

sidered. The curves applying to this case are shown in

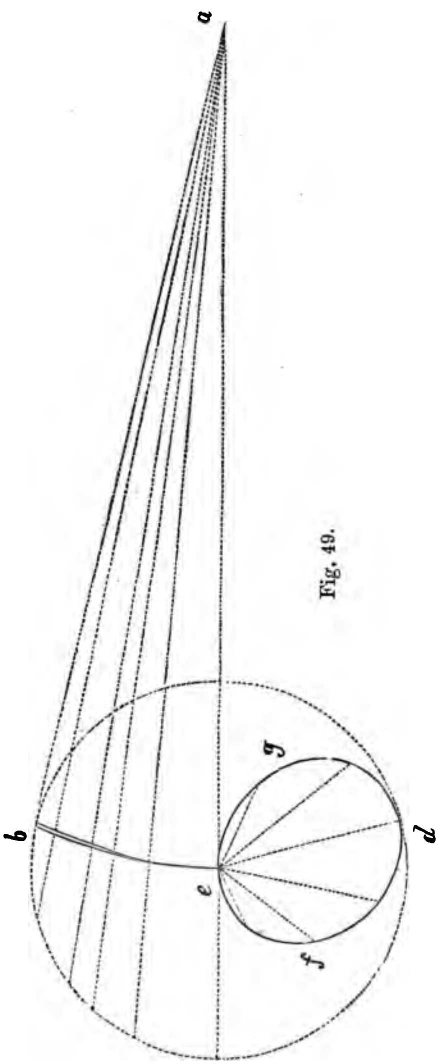


Fig. 49.

Fig. 49. The point *a* is the axis upon which the cylinder vibrates; *b e* the curve described by the points upon which the perpendiculars fall for each position of the crank; *e f d g* exhibits the variation of the ultimate moment of power about the centre *e* for one stroke. It is evident from these diagrams that the action of the oscillating engine is more uniform than that of the fixed cylinder engine, as the solid illustrating the action of the crank in the former machine will be of uniform thickness throughout. In these investigations relating to the action of the crank I have assumed the

effective pressure on the piston uniform throughout the stroke.

When a beam-engine is used to give rotatory motion the piston-rod is connected with one end of the beam, and the connecting-rod with the other.

The pumps consist of cylinders fitted with plungers; their action will be described subsequently.

The valves regulating the admission and emission of steam to and from the cylinder are automatically worked by the engine itself, the motion being generally imparted through an excentric wheel fixed upon the main shaft of

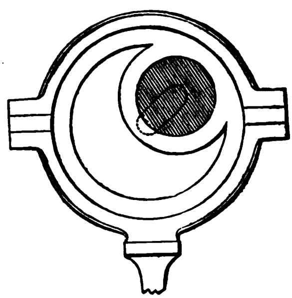


Fig. 50.

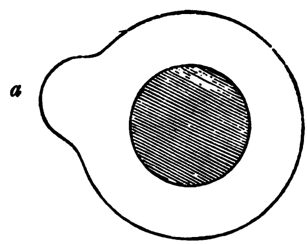


Fig. 51.

rotatory engines; the excentric is shown, Fig. 50. Its action is equivalent to that of a crank, which crank is indicated by the dotted lines.

When an intermittent motion is required, a contrivance called a cam is made use of, one form of which is shown, Fig. 51. The extended part *a* of the cam lifts a lever at every revolution, the lever falling as soon as this part of the cam has passed.

The last part of the steam-engine to be mentioned in this chapter is the fly-wheel, used to regulate the motion of the machine, by absorbing the energy during some parts of the revolution and giving it up during other parts.

CHAPTER IX.

DETAILS OF STEAM-ENGINES.

CYLINDERS AND VALVES.—Cylinders are divided into two classes, fixed and oscillating. Fig. 52 represents a vertical section of an ordinary fixed cylinder, taken through the centre in such a direction as to show the steam passages; *a* is the body of the cylinder, *b* and *c* are the covers. The ends of the passages through which the steam passes from the steam-chest to the interior of the cylinder are shown at *d* and *e*, *f* showing the entrance to the exhaust-pipe through which the steam, having done its work in the cylinder, escapes to the condenser or atmosphere. These entrances are called ports. The body of the cylinder is made with

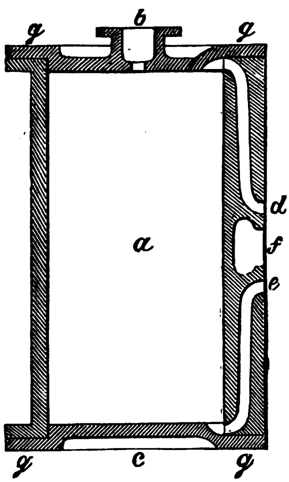


Fig. 52.

rims (called flanges) at the top and bottom, to which the covers are attached by bolts and nuts at *g g g g*.

Fig. 53 is a vertical section of an oscillating cylinder, taken through the trunnions upon which it vibrates, and through which the steam passes, on one side *from* the *boiler*, on the other *to* the condenser or atmosphere; *c c c c*

are the flanges, the covers are not shown; *a* and *b* are the trunnions, diametrically opposite each other, and having

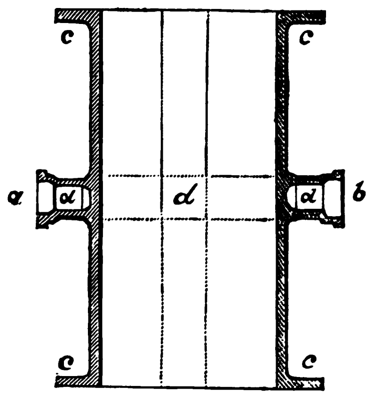


Fig. 53.

turned parts, called journals, which rest in the bearings upon which the cylinder oscillates.

Fig. 54 is an horizontal section of the cylinder taken

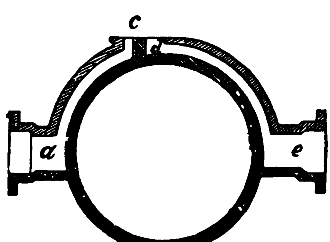


Fig. 54.

through the band that conducts the steam from and to the trunnions; *a* and *e* are the trunnions. The steam from the

boiler enters the steam chest at *c*, and that leaving the cylinder exhausts through the port *d* and the trunnion *e*.

The STEAM PORTS attached to and forming part of the cylinder are shown, Fig. 55. A is a section taken through the cylinder, that part only which shows the ports being illustrated. B is a front elevation of the ports, and C a section on a plane cutting the steam passages vertically; *a* is the interior of the cylinder; *b* and *c* are the steam ports or external openings of the steam passages, which are

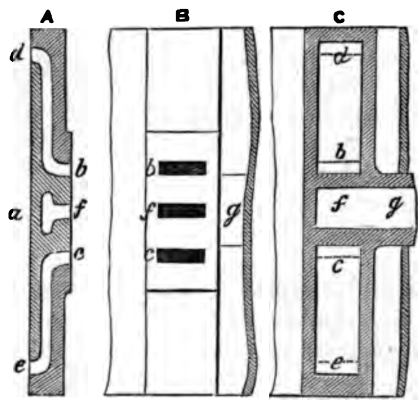


Fig. 55.

made narrow in order that they may be opened and closed by a slight movement of a plate lying over them, this moving in the direction *b c*; *f* is the port into which the exhaust steam passes, and whence it escapes by the exhaust-pipe *g*.

The THICKNESS OF METAL in the cylinder must be proportioned to bear the bursting stress, and also the vibratory strains to which that detail is subject. The following formula is based upon engines found practically satisfactory.

Let $t =$ thickness of metal in eighths of an inch; $d =$ diameter of cylinder in inches; $p =$ maximum pressure in lbs. per square inch, then $t = \frac{p\,d}{440} + \sqrt{d}.$

WROUGHT-IRON BOLTS FOR CYLINDER COVERS.—Let $n =$ number of bolts in cover, D = diameter of bolts in inches; $D = \frac{d}{75}\sqrt{\frac{p}{n}}$. The thickness of the nuts is usually made equal to the diameter of the bolt.

CYLINDERS AND CHEST COVERS.—Let $t =$ thickness in inches; if curved, $c =$ rise of cover in inches; $t = \frac{p\,d^2}{14400\,c}$ and $c = \frac{p\,d^2}{14400\,t}$. If flat, let $l =$ length of shortest side (or diameter if circular) in inches; $t = \frac{l}{120}\sqrt{p}.$

AREA OF STEAM PORTS.—$s =$ speed of piston in feet per minute; $p =$ *absolute* pressure in lbs. per square inch in cylinder; $P =$ *absolute* pressure in lbs. per square inch in boiler; $a =$ area of port in square inches. $a = \frac{d^2}{15000} \times s \times \sqrt{\frac{p}{P-p}}.$

The drawings being prepared, the pattern maker will proceed with the template and core-boxes; if large the cylinder will be cast in loam, otherwise it may be cast in sand. The cores for the steam passages should not be carried quite through the metal, a film being left so that the port edges may be cleanly cut on the port faces. The modes of casting are described in Chapter III. The cylinder being cast and trimmed, passes into the hands of the turner, to be bored and have the flanges faced in th

lathe. The *boring head* used is shown, Fig. 56. It is of cast iron accurately bored in the centre and turned on the periphery. The boring bar upon which it travels is shown by the shaded part at *f*; *e*, *e*, *e*, &c., are slots in which the boring bits are fixed by wedges, the boring head being slightly less in diameter than the cylinder to be bored. The head is first used with the bit shown at *a* and *b*, which acts almost as a scraper, but is sufficiently accurate in its action to take the rough cuts.

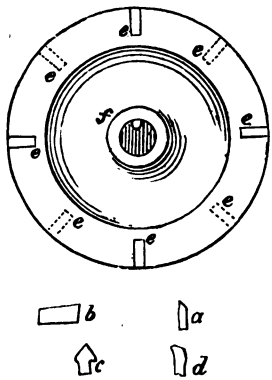


Fig. 56.

The finishing cut is taken with the point tool shown at *c* and *d*; and in taking this cut it must be remembered that, as by the friction of boring the cylinder becomes heated, the operation should not be stopped (for a sufficient time to allow it to cool and contract) until the cut is taken right through the cylinder. It will be found that leaving the film of metal over the ends of the steam passages facilitates the boring and prevents damage to the tool, by coming in concussion with the edges of the holes that would present themselves were the passages carried through in the casting. The interior of the cylinder finished with the point tool presents the appearance of a screw of extremely fine thread, hence at first there is a great deal of friction between the cylinder and the piston. In a few days the roughness wears off and the inside of the cylinder becomes smooth and bright. A friction diagram, that showing the steam pressure requisite to drive the engine *unloaded*, should therefore not be taken until the engine has been at work a week or two.

After boring, the flanges of the cylinder must be "faced," which may be done by attaching a temporary slide apparatus to hold the cutting tool, in order to allow a motion of the same from the interior towards the exterior of the cylinder, the cut being commenced at the internal edge of the flange.

The port faces must now be planed, and then faced by the processes previously described, up to a true surface, and such bolt holes as are required drilled.

If the cylinder is intended to oscillate the trunnions must be accurately turned inside and out. The cylinder covers must be faced to fit the flanges of the cylinder, and

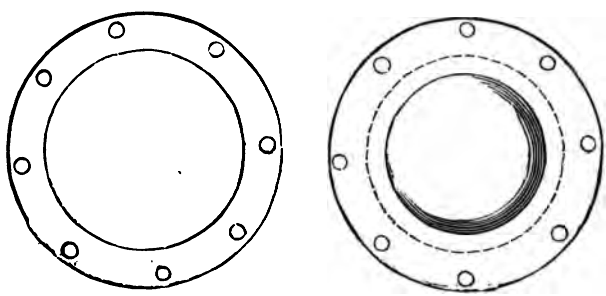


Fig. 57.

also turned on the periphery. An end view of the cylinder and plan of the bottom cover are shown, Fig. 57. The bolt holes must be drilled in the covers to correspond with those in the cylinder flanges.

I will now describe the STUFFING BOX AND GLAND through which the PISTON-ROD passes, first, however, giving a rule for finding the diameter of the latter. (This diameter will also do for the connecting-rod.) D = diameter of piston-rod; $D = \frac{d}{50} \sqrt{p}$. Fig. 58 shows a vertical section of a stuffing-box and gland. *c d* is the rod which is required to

work air and steam tight through the plate *a b*. Upon this plate, and in one piece with it, is cast a cylindrical box, with a flange *e f*; this, which is the stuffing-box, is bored at the bottom to fit accurately the rod *c d*, being at the upper part bored out larger, as shown, so as to have a cylindrical cavity round the piston-rod. To this box is fitted the gland, with a flange *g h*, which gland is bored throughout its length to fit *c d*, and its exterior surface turned to fit easily in the stuffing-box. A closed space *i i* will then exist around the rod *c d*, and this is filled with greased hemp or other steam-tight packing.

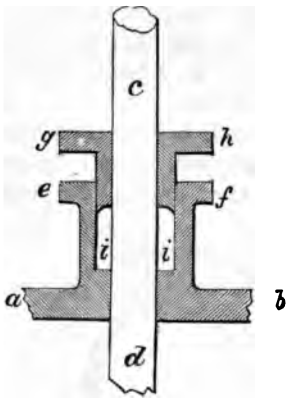


Fig. 58.

The packing is pressed against the rod *c d*, by forcing the gland into the stuffing-box by means of bolts connecting the flanges *g h* and *e f*; or in small boxes the gland has a thread cut on it to fit one cut in the stuffing box, so that the former can be directly screwed down on the packing.

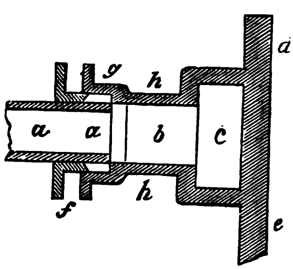


Fig. 59.

Figs. 59 and 60 show sections of two kinds of trunnions, upon which the cylinder oscillates, and through which the steam passes. *d e* is a portion of the cylinder, *c* the steam band surrounding it, *b* the interior of the trunnion, *h h* the portions embraced by the trunnion bearings whereby the cylinder is supported, *a a* the extremity of the steam-pipe. The steam-pipe

is at rest, while the trunnion oscillates so that it has a circumferential motion about the steam-pipe. In Fig. 59 the joint is made steam-tight by enclosing the extremity of the steam-pipe in a stuffing-box, as shown. In Fig. 60 the steam-pipe and trunnion are faced, and a steam-tight joint made by a spring ring in the groove *i i*. The former arrangement is least liable to get out of order.

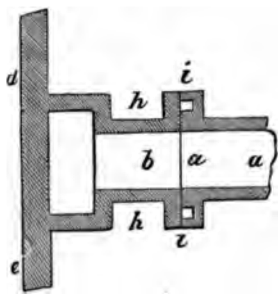


Fig. 60.

I shall now describe some of the various forms of SLIDE-VALVES, used for regulating the passage of the steam to and from the cylinder; first giving a rule for the diameter of the valve-rod. Let l = length of slide in inches; b = breadth of slide in inches; D = diameter of rod in inches:

$$D = \frac{\sqrt{l\ b\ p}}{100}.$$

Fig. 61 shows the simplest form of slide-valve in vertical section, and also the valve itself in plan or back view. This valve is a box rectangular in form, as shown at $f f'$; h' is the valve-rod, having a head to slip into a recess in the valve, so that although it drags the valve back and forward on the port faces, does not *lift it off them*. In the vertical section $a\ b$ is part of the interior of the cylinder, the steam passages opening into it at a and b; x is a part of the piston; c and d are the external steam-ports, e being a port leading to the exhaust (for front view of port faces see Fig. 55); upon the port faces the box $f f$ slides; its width is sufficient to cover the ports, and its length such as to cover one steam-port and the exhaust-port. $k\ k$ is the *steam-chest* bolted to the port faces, and into which the

steam enters from the end of the steam-pipe, shown at *l*. The valve-rod works through a stuffing-box at *n*. The valve is kept up to the port faces by the pressure of steam in the chest *k k*, which is always in excess of that within the valve, the inside of which is *always in communication with the exhaust-port, e*. When the valve is in the position shown, the steam is passing from the chest *k k* into the bottom of the cylinder through the passage *d b*, the steam

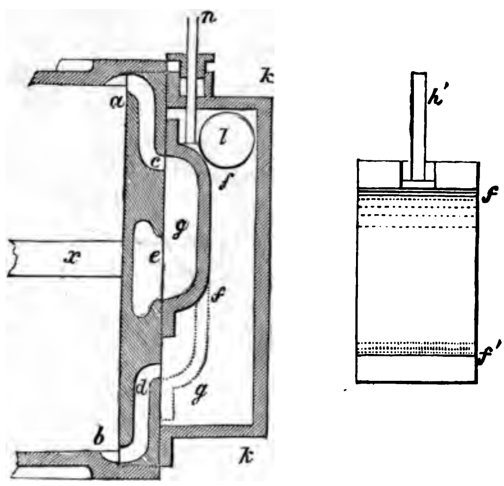


Fig. 61.

from the top of the cylinder is exhausting through the passage *a c* and the inside of the valve and the exhaust-port *e*. When the valve is moved into the position of the dotted lines *g*, the direction of the steam will be from the chest to the top of the cylinder, and from the bottom of the cylinder to the exhaust. Thus by moving the valve *alternate reciprocating* motion is given to the piston; but it *is necessary* the valve should *so open* that the engine cannot

reverse the motion of its fly-wheel at the end of the stroke; for this purpose the valve is made to open a little before the piston reaches the end of its stroke; the valve is, in fact, in advance of the piston, and were the engine accidentally to reverse, the valve would turn back and close the port it had already partly opened, re-opening the one it had just closed to the steam. This is called giving LEAD to the valve, and the direction of motion of the engine will depend upon the direction in which this lead is given. We can then reverse the engine by shifting the excentric on the shaft, or by means of a link-motion, to be subsequently described.

In order to cut off the steam at an earlier period than would be done if the valve edges only just covered the ports, these edges are extended, as shown, giving what is called LAP to the valve. This does not allow a variable expansion in working the engine, which if required must be obtained by an independent valve, cutting off the steam before it reaches the ordinary slide-valve, and known as an expansion-valve. In some engines (such as locomotives) these valves are made very short, in order to reduce their travel; the slide is then surrounded by a square frame *formed on the* slide-rod, the latter for better guidance

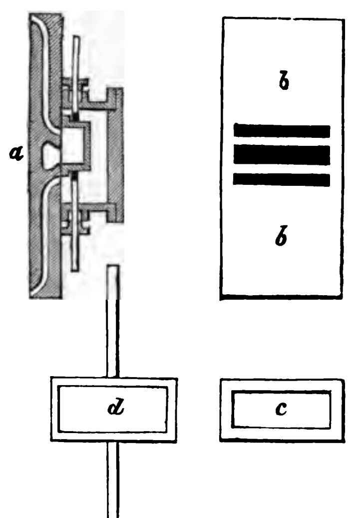


Fig. 62.

passing through both ends of the steam-chest, or valve-jacket. Such a valve is shown, Fig. 62; *a* is a vertical section, *b b* a front elevation of the ports, *c* an inside view of the valve, and *d* the slide-rod and frame.

Fig. 63 shows vertical and horizontal sections of a long form of slide-valve; it is a tube with faces at each end. *a* and *b* are the steam passages leading to the steam cylinder, *k* a hollow in the metal to lighten the cylinder casting, *d e* is the slide, *f f* the steam-chest, and *g* the slide-rod; *c* is the exhaust. Heavy slides like this, placed vertically, should have their weights taken by counter-balances. With the valves in the position shown, the steam entering at *v* will pass round the slide and into the bottom passage *b*; that in the top of the cylinder passing from *a* through the tube of the valve *e d* into *c* the exhaust. Raising the valve to the position shown by the dotted lines, the steam will pass into the top passage *a* and exhaust from *b* into *c*, the lower face of the valve being long enough to cover both the ports *b*, *c*. At *m* is a horizontal

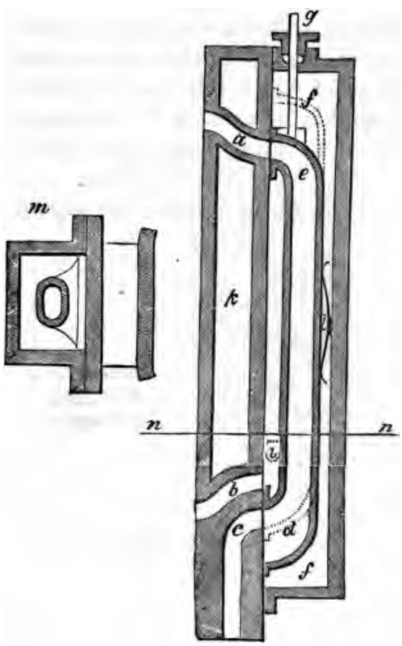


Fig. 63.

section on the line *n n*; *l* is a light spring, to prevent the valve from falling off the ports when the steam is off.

In Fig. 64 are shown views of the D valve. *a* and *b* are the steam-passages to the cylinder, *c* and *d* are two D-shaped

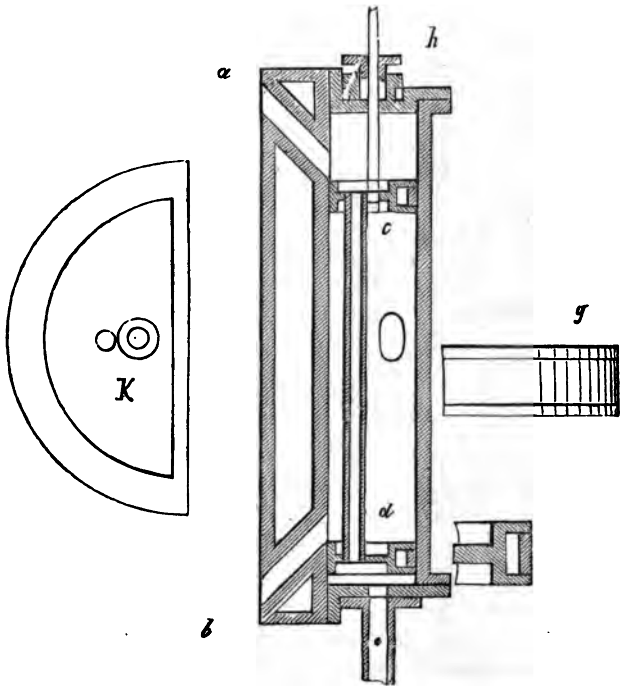


Fig. 64.

slides, as shown in plan at *k*—these slides being connected by an open pipe, *e* is the exhaust, *g* a side elevation of one slide. The D-shaped slides are accurately fitted to the steam-chest, which is truly shaped up, being made steam-tight at the back by metal slips pressed against the steam-chest by springs. The slides are moved by a rod, *h*; the

steam is admitted between the D-shaped slides, and in the position shown is passing through the passage *b* to the bottom of the cylinder; that in the upper part of the cylinder is exhausting from *a* through the pipe *cd* into *e*. If the slides be

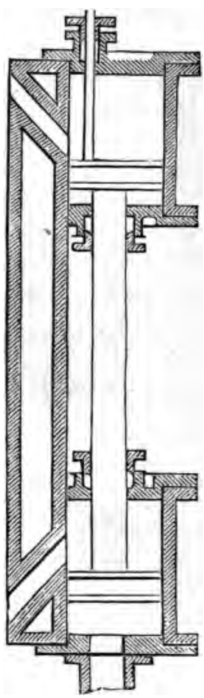


Fig. 65.

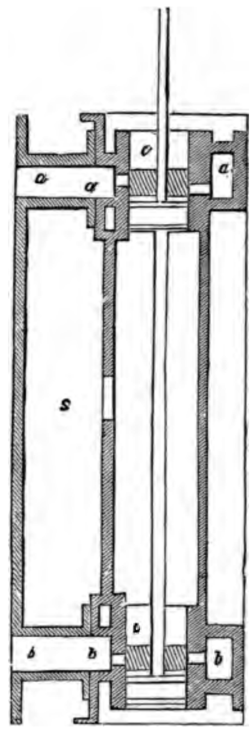


Fig. 66.

now raised above the ports, the steam will flow in at *a* and out from *b* into the exhaust, *e*. It is not necessary in this form to make the steam-chest continuous; it may be made in two, with suitable stuffing-boxes, as shown, Fig 65.

Another form of long valve is shown, Fig. 66. The

valves consist of two round slides, or pistons, fitted with packing rings pressed out by springs. The steam is admitted at *s* between the slides. Round the valve-jacket at each end is a casing communicating with the exhaust; and nearer the centre of the jacket there are circular passages *a a*, *b b*, communicating with the steam-ports *a* and *b*. Diagonal slits, *c c*, open a communication between the steam-ports and the interior of the steam-chest. In the position shown, the steam admitted at *s* is passing through the lower set of diagonal slits into

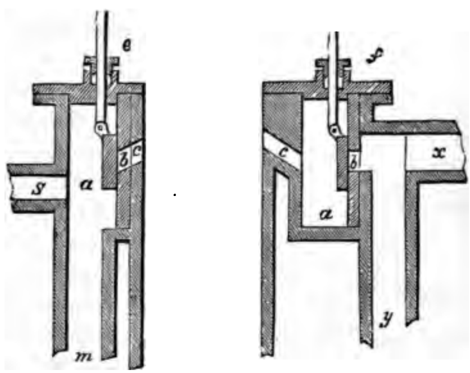


Fig. 67.

the steam-passage *b*; and the steam in the upper part of the cylinder is passing from the passage *a a* through the upper series of slits, and out at the top end of the valve-jacket. If the valves be moved up, past the diagonal slits, the direction of the steam will be reversed. Sometimes two sets of valves are used, one for the steam and the other for the exhaust. These slides are flat plates fitting steam-tight to the port faces; this arrangement is shown, Fig. 67: *e* is a steam and *f* an exhaust-slide. In *the former, s is* the steam-pipe, *a* the slide, c the upper

steam-passage, and *b* the port face; at *m* the steam-pipe is continued to supply the lower valve; as shown the valve is closed. At *f*, the exhaust-slide, *c* is the upper exhaust-passage, *a* the slide, *b* the port-face, *x* the exhaust-pipe, and *y* a pipe communicating with the lower valve.

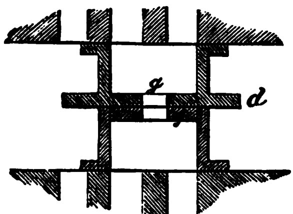


Fig. 68.

Fig. 68 shows in horizontal section an arrangement in which the slide-valves for the two cylinders of a locomotive engine are placed in one steam-chest. One slide has a plate, *d*, cast on its back and surfaced parallel to the working face; the other slide has an open box cast upon its back to receive the piston *f*, having an upper surface also parallel to the working faces; the piston *f* also fitting steam-tight in its box, and its top face bearing steam-tight against the face of the plate *d*. By this arrangement the valves are relieved from part of the steam pressure, and to assist the free exhaust, ports *g* are formed in the backs of the valves to allow the steam exit through both exhaust-ports.

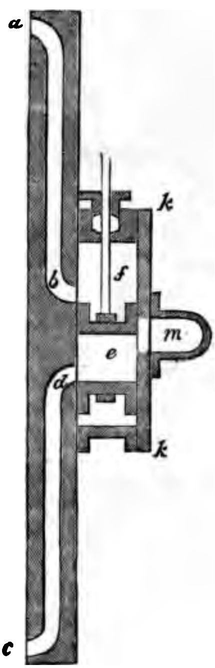


Fig. 69.

Fig. 69 is a vertical section of an equilibrium-valve entirely relieved from the steam pressure. *a b* and *c d* are the steam-passages, *e* the valve, *k k* the steam-chest, and

m the exhaust-pipe. The slide-valve works accurately between the port-face and the interior of the steam-chest, being kept steam-tight by packing-rings on the back, which are pressed against the inside of the steam-chest by springs. All faces working together must be accurately surfaced. This valve is evidently in equilibrium, as the steam-pressure affects it equally in both directions. In the position shown the steam is passing into *b a* and exhausting through *c d e m*.

In Fig. 70 is shown a vertical section of another form of equilibrium-valve, which in principle is almost identical with the long D-valve. *a* and *b* are the steam-passages, *c* the valve, having a cavity corresponding to that of the short slide, but having at its back a semi-cylindrical tube, packed to fit the steam-chest steam-tight. The steam in the position shown is passing from the inlet, *s*, to the top passage *a*; and the steam from the lower end of the cylinder is exhausting through the cavity, *c*, of the valve. When the valve is lifted, the steam traverses its length and enters the passage *b*, the steam in the top of the cylinder then exhausting through the cavity *c*. *e* is a plan of the valve, and *f* a section on the line *c*, *d*.

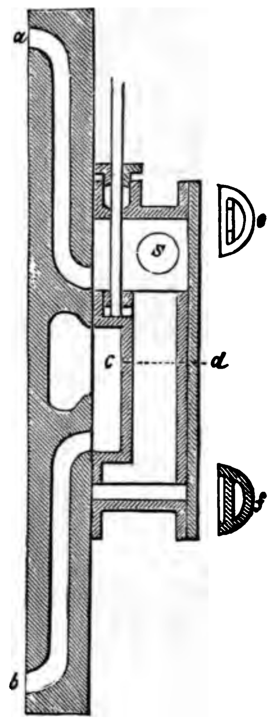


Fig. 70.

I will now describe a slide-valve for a compound engine.

In Fig. 71 two cylinders are shown in section, being of different diameters. Of these cylinders *a* is smaller than *b*. If high-pressure steam be used in *a*, and after one stroke of the piston has been made, a communication be opened with one extremity of the large cylinder, the steam will pass out of the small cylinder into the larger one, because, although the two pistons move together, it can expand by so doing.

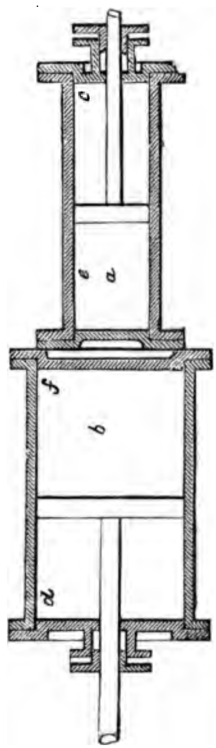


Fig. 71.

Let it be required to construct a valve so that the course of the steam may be as follows:—First, say, into the end *c* of the small cylinder, thence into the end *d* of the large cylinder, and thence into the exhaust. Then the steam which passes into the end *e* of the small cylinder will pass thence into the end *f* of the large cylinder, and thence to the exhaust. The valve arrangement required is shown in Fig. 72. *a* and *b* are the ports to the large cylinder, *c* and *d* those to the small one, *e* the steam-port, and *f* the exhaust. The valve consists of a rectangular block of metal, kept upon the port faces by rollers, acted on by springs; and in this rectangular block certain rectangular passages are cut, or cast: *i* and *j* are recesses, similar to those in short slide-valves, and *k l* is a long passage, similar to that in the long valve. In the position shown in the figure, the movement of

the steam is as follows:—From the steam-port *e* the steam is passing through the recess *j* into the lower port *c* of the small cylinder; the steam in the upper part of the small cylinder is passing from the port *d*, through the long passage *k l*, into the front part of the large cylinder; and the steam in the lower part of the same is issuing from the port *b*, through the recess *i*, into the exhaust-port *f*. If the slide be now moved to the right, the steam will then pass from the port *e*, through

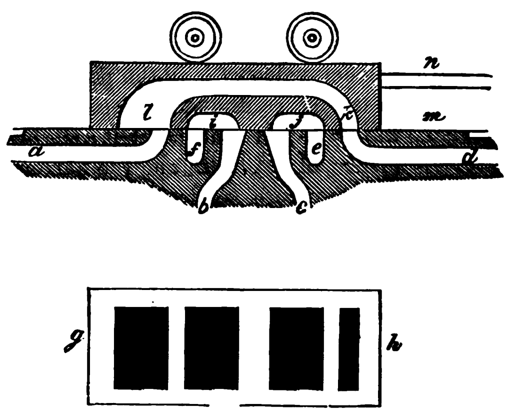


Fig. 72.

the recess *j*, into the port *d*; from the port *c*, through *i*, into the port *b*, and from the port *a* into the extremity *l* of the long passage, and out at the exhaust *f*; it cannot pass out at the end *k* of the passage, as that will be closed by contact with the part *m* of the port-face. *n* is the slide-rod; *g h* is a front view of the slide-valve.

There are many varieties of slides for compound engines, some of which show great ingenuity, but the above may be taken as a type.

I have referred to the use of a separate expansion-valve; a section of one is shown in Fig. 73. *a b* is the slide-valve jacket, or steam chest, within which the slide-valve works as usual; the steam is not admitted direct to this chest, but to another one, *c d*, placed at the back of it. *e f* is a flat plate of metal accurately surfaced and fitted to a port on the back of the slide-jacket, in which a number of slits are made corresponding to a similar number of slits in the plate *e f*. While the expansion-valve *e f* is in the position shown in the figure, the steam passes freely into the slide-valve jacket; but a slight movement will cut it off, and the narrower the slits the more suddenly can the steam be cut off. This valve may be worked by an excentric, but is more commonly actuated by a cam, of which a special form will subsequently be illustrated.

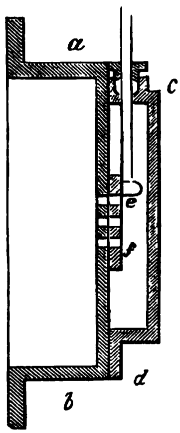


Fig. 73.

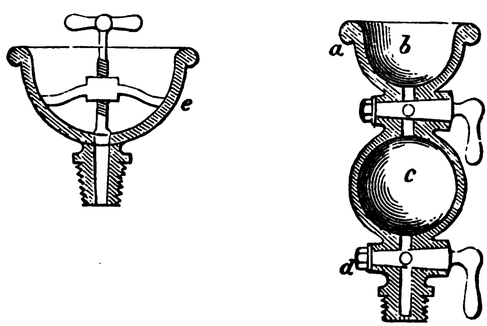


Fig. 74.

In order to lubricate the working parts both in the cylinder and slide-jacket, grease-cocks are required, and of

these two common forms are shown in section in Fig. 74. *e* is a valve suitable for condensing engines; it is screwed into the cylinder cover and used as follows:—The cup is closed by a valve actuated by a screwed handle as shown; this valve is raised as the piston ascends, when there is vacuum in the top of the cylinder, and grease is sucked in, the valve being closed before the engine turns the centre. In using the cock *a*, grease is poured into *b*, then by turning the stop-cock between *b* and *c*, it flows into the reservoir *c*. This stop-cock is then closed and *d* opened, when the grease flows into the vessel to be lubricated.

PISTONS.—Fig. 75 illustrates a simple form of steam-engine piston. The top view is an elevation, the next a vertical section, and the third a plan: *a* and *b* are the top and bottom surfaces of the piston; *g h* is a cut packing-ring, which, by pressing against the surface of the cylinder, keeps the piston steam-tight; *c d* is a tongue to prevent the steam leaking through the cut in the packing-ring. *e f*, in the section and plan, is the body of the piston; *i i* the junk ring, which holds the packing-ring in position, being attached to the body of the piston by bolts. *k* is a hole in which one end of the piston-rod fits. It will be observed that the packing-ring is not of equal thickness throughout, being made thinnest at the point where it is cut through and thickest at a point diametrically opposite, the object being that the packing-ring may press equally against the cylinder all round. It is commonly made of cast iron.

In making the piston, the aperture *k* should first be bored out, and a rod fitted to it; by which it is carried between the lathe centres, while the body is accurately turned. It is then drilled and tapped to receive the junk ring-bolts, which do *not* pass through the body of the piston but screw into it. The upper surface of the flange of the piston is scraped and faced to fit the packing-ring, and the *lower surface* of the junk-ring is similarly treated. The

upper and lower edges of the tongue piece are also fitted in a similar manner to the surfaces with which they are in contact.

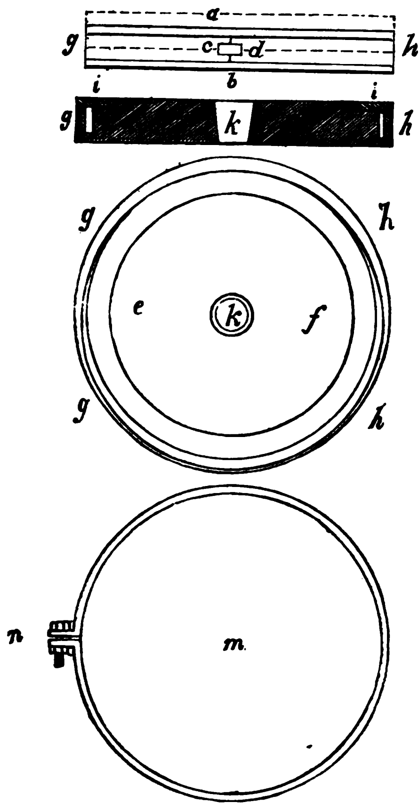


Fig. 75.

The packing-ring (in order that it may press against the cylinder) is turned of rather greater diameter than the cylinder, and a layer cut out on the thin side, and one end of the tongue secured to one side of the cut part of the ring. As when out of the cylinder this ring will have its natural diameter, it must be squeezed together to get it in place: this is done by means of the wrought-iron hoop *m*, which is placed around the piston so as to embrace half its depth, as shown by the dotted lines at *g h*; it is then tightened up by the bolt and nut at *n* until the packing-ring's diameter is enough reduced for its lower half to be pushed into the cylinder; the hoop *m* may then be removed,

as the lower half of the packing-ring being now in the cylinder it cannot again expand, and *m* being removed the piston can then be pushed into the cylinder completely. The packing-ring should only press lightly upon the cylinder, otherwise the wear and tear and also the loss of power by friction will be unnecessarily great.

Large pistons do not have their bodies cast solid, but are hollowed out, one form of such piston (with the junk-ring removed) being shown in Fig. 76. *a* is the hole in the

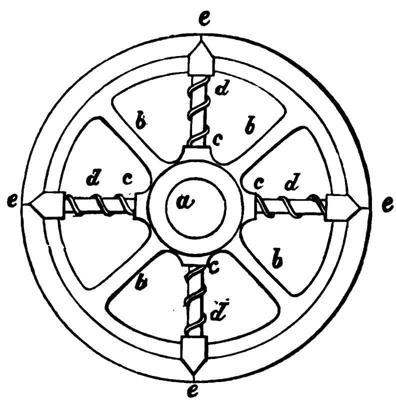


Fig. 76.

"boss" or centre of the piston, in which the piston-rod is fixed; from this boss arms *b* and *c* run to the periphery, being, of course, cast in one piece with the bottom plate of the piston; *c c c c* are stops against which spiral springs, guided by rods *d*, abut; by the pressure of these springs the wedge pieces *e* are pressed outwards, and so press the segments of the packing-ring against the surface of the cylinder.

Figs. 77 and 78 show other arrangements of springs for pressing out the packing-rings, either cut or in segments.

In the former *a* is the piston-rod hole, *b c d* a cut ring, and *e e e e* arms carrying springs *f f f f*, to press the packing-ring against the cylinder. In Fig. 78 the arms *b b b b*

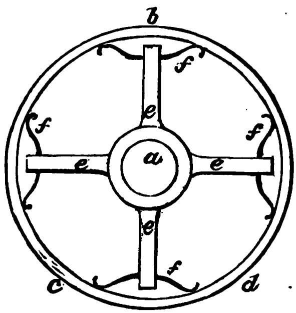


Fig. 77.

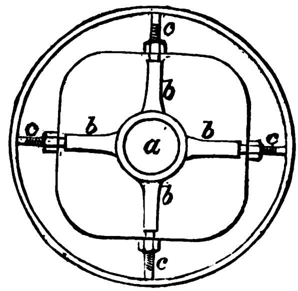


Fig. 78.

carry studs *c*, which, by means of nuts, press upon and distort an elastic ring, which, reacting, forces the studs against the packing-ring. Fig. 79 illustrates a very simple form of piston much used for pistons of moderate diameter. *d* is the piston-rod socket, *e e* the body of the piston, and *a b c* narrow grooves ¼ inch to ½ inch wide, in which are inserted narrow spring-rings to press against the cylinder.

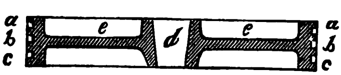


Fig. 79.

The piston-rod is turned taper at its lower end to fit the cavity in the piston, and it is there secured by a nut on the end, or by a pin or key driven through the boss and the piston-rod.

Piston-rod Heads.—The top of the piston-rod will be variously formed according to the kind of engine for which it is required. In some cases it will be directly jointed to the connecting rod, in others it may be connected with a

beam, or rocking lever, or other element. In Fig. 80 A and B are front and side elevations, suitable when the piston-rod is immediately jointed to the connecting-rod. *a* is the end of the piston-rod which passes into the tubular part *c*, where it is secured by a key or cotter, shown passing through the work. The cross-head is forked above to admit the end of the connecting-rod, and the forked ends have cylindrical apertures *b* bored through them to receive the pin which joins the piston-rod to the connecting-rod.

C and D are elevations of a cross-head used with beam engines: the part *c* is perforated and traversed by the extremity *b* of the piston-rod; *a a* are accurately turned "gudgeons," on which move the ends of the links connecting the piston-rod with the main beam.

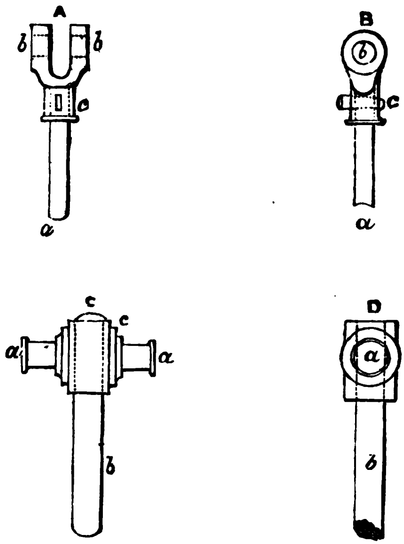


Fig. 80.

In Fig. 81, at A, is an elevation of a cross-head formerly used for side lever marine engines; but these are now out of date. *a* is the end of the piston-rod passing through the perforation *b* of the cross-head *c c*; *d d* are gudgeons carrying the extremities of links. C and D show heads used when the piston-rod is jointed directly to the crank, *as in oscillating* engines. *a* is the piston-rod, *b* the socket

in the head, *c* and *d* "plummer block" and "cap" of the cross-head, connected by bolts and containing the bearings by which the crank-pin is to be embraced, *e* the hole of the crank-pin. At D brass bearings are shown to receive the crank-pin, but C being supposed to be of brass, no such bearings are requisite.

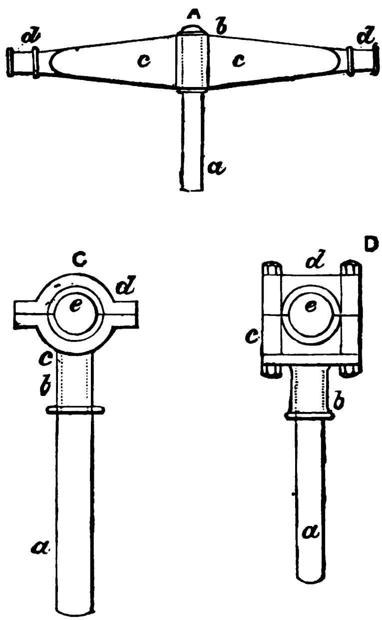


Fig. 81.

In Fig. 80, C is similar to a cross-head used in locomotives and some other kinds of engines. The square part of the cross-head is made with small ridges or guides, as shown by the dotted lines, parallel to the piston-rod; this block moves between accurately planed guides, and the protruding journals *a a* carry the ends of a forked connecting-rod. This cross-head is sometimes at the extremity of the piston-rod and sometimes further on, when the extension of the piston-rod beyond the guide-block is required to work part of the machinery. The cross-head shown at A generally has the connecting-rod pin prolonged to carry guide-blocks at its extremities, which move between suitable guides.

Connecting-rods.—In Fig. 82, A shows a form of connecting-rod commonly used when the piston-rod directly joins the connecting-rod. It consists of a spindle *a*, having at each end bearings *b b*, retained in position by straps

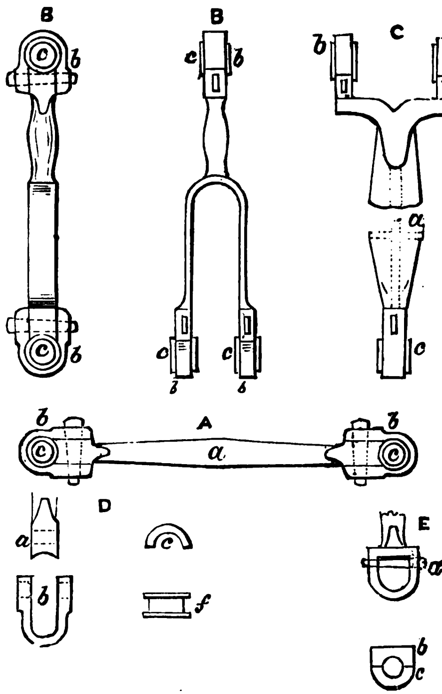


Fig. 82.

fixed by wedges and keys passing through them and through the extremities of the spindle. To these straps, however, I will return. B shows a connecting-rod of the forked description as used with the single guide-block; *this also is* furnished with straps and bearings at the ends.

C is an elevation of a connecting-rod frequently used for beam engines; it is broken off to save length in the illustration, the upper and lower ends only being shown. *a* is a round spindle when wrought iron is the material used, but of an + section, as shown by the dotted lines, when the rod is made of cast iron. At *b b* are two bearings similar to those already mentioned, which embrace the journals of a pin in the main beam; *c* is the crank-pin bearing. D shows bearings of the first kind, *a* being the end of the connecting-rod; *b* the strap; *c* and *f* elevation and plan of brass bearings. E shows the second kind of bearing used with the rod C. *a* is the end of the connecting-rod into which bearings *b* and *c* are passed, after which they are passed over the crank-pin and then tightened up by the wedge shown dotted at *a*.

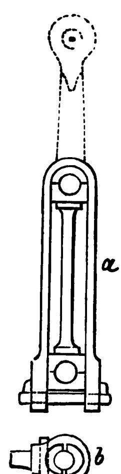


Fig. 83.

MOTION LINKS.—In Fig. 83, *a* shows a form of link consisting of a long strap, in which two sets of bearings furnished with ridges to guide them are placed and keyed up tight, being retained at their proper distances by a strut or distance-piece, as shown. *b* shows the extremity of a link, which is bored out at the end larger than the bearings, which are inserted placed around the journal on which they are to work and keyed up tight.

MAIN BEAM.—This element was formerly (after the days of timber beams) always made of cast iron, but the advantages of using wrought iron are now thoroughly appreciated, being a lighter and more reliable material. For small engines, however, cast iron is still used. A cast-iron beam is shown in Fig. 84, in elevation, plan, and section. At the centre

a is a gudgeon upon which the beam is supported; *b* is a gudgeon connected with the piston-rod, and *c* one for the connecting-rod; *d* and *e* are other gudgeons to carry pump-rods, &c. At *g* is a section of the beam

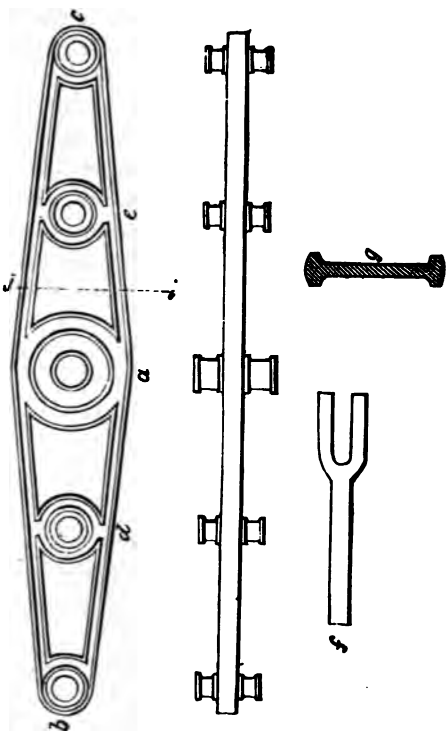


Fig. 84.

taken through *j i*. At *f* is shown in plan the end of a forked beam. The proportions to be adopted where no special circumstances interfere are as follows: — The stroke of the piston twice the diameter of the cylinder; the beam three times the length of the stroke; and its

depth at the centre equal to the diameter of the cylinder; length of connecting-rod from twice to thrice the length of the stroke. The following rule will give the thickness of the beam at the centre. p = maximum pressure per square inch on piston; D = diameter of cylinder in inches; d = depth of beam in inches; l = length from centre of gudgeon b to centre of gudgeon a in feet; t = thickness of beam in inches, then $t = 0{\cdot}02 \times p \times l \times \left(\frac{D}{d}\right)^2$.

If the beam is of cast-iron, the manipulations, after it has left the foundry, are not very extensive, for all that remains to be done consists in boring the apertures to receive the gudgeons and fitting the latter to the beam.

Fig. 85 shows a section of a shaft firmly fitted into a

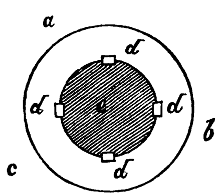


Fig. 85.

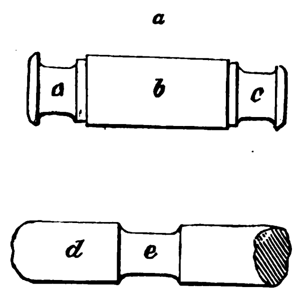


Fig. 86.

cast-iron ring or boss: e is the shaft and $a\ b\ c$ the boss; it is bored to fit accurately the shaft, which has been previously turned, and in both the boss and the shaft certain slots are made to admit keys $d\ d\ d\ d$, which keys prevent the shaft from revolving within the boss. This is the mode in which the gudgeons are fixed in the bosses of the main beam.

a, Fig. 86, represents an elevation of a gudgeon; in some cases it is not absolutely necessary to turn the centre part

b, which is keyed into the boss; but in all cases the journals *c c* must be accurately turned. *d* represents a part of a shaft having an ordinary form of journal to run in bearings shown at *e*. I will next describe the construction of BEARINGS generally, shown at Fig. 87.

a is a solid block of cast iron having a recess (half round, as shown, or rectangular) on its upper side; it is called a PLUMMER-BLOCK. This is surmounted by a cast-iron cap *b*, having a semicircular notch in its lower side; the two are connected by bolts. The general form will be recognised from the resemblance it bears to some kinds of piston-rod heads. Between the plummer-block and cap, brass or gun-metal bearings are placed, of which sections are shown at *d* and *e*, the latter for a plummer-block having a square notch. *e* is first placed in the plummer-block, the shaft then laid in it, the top brass *d* placed upon it, and the whole covered by the cap, which is bolted down to the plummer-block. The brasses are made with flanges to prevent their sliding out of their proper positions. *f* is a vertical section through the brasses and plummer-block when put together, the journal being omitted. The brasses require to be accurately bored out, and then fitted to the corresponding journals by scraping. Various forms of plummer-blocks and brasses are used, but the one described will convey a general idea of the principle involved in their construction.

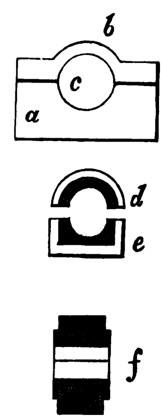


Fig. 87.

Fig. 88 shows the general form of one class of CRANKS; those that are not made in one piece with the crank-shaft. *Cast-iron cranks* are frequently used for small engines,

but wrought iron is preferable, and for large cranks the latter should always be used. The figure shows a front elevation and a vertical section of the crank. It must be planed on the face, and at right angles to this face two apertures are to be bored, *a* to receive the end of the main shaft, *b* that of the crank-pin. In fixing the crank upon the shaft, keys are to be used, and the crank should also be forced on by hydraulic pressure (in this case the end of the main shaft has a *very slight* taper) or shrunk on. In the latter case the crank is bored out slightly less than the diameter of the crank-shaft, it is then heated until, by its expansion, it will admit the end of the shaft, which being put in position, the crank cooling contracts, and firmly grips. Cast iron cranks will not stand this treatment with any amount of certainty. Cranks for inferior purposes are sometimes made by bending the crank-shaft to the required form, but for sound work the crank should be forged solid on the shaft, and planed or slotted out to shape.

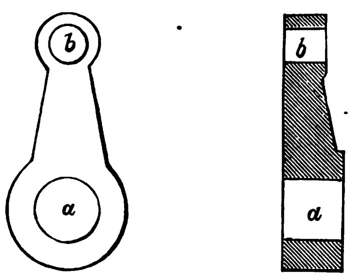


Fig. 88.

Three forms of CRANK-SHAFT are shown in Fig. 89. The minimum diameter of the crank-shaft may be found from the following formula. Let $d =$ diameter of shaft in inches; H P = horse-power of engine (calculated for maximum pressure, *not mean pressure*); N = number of revolutions of engine per minute; then $d = \sqrt[3]{\frac{320 \text{ H P}}{\text{N}}}$. *a b* show two parts of a crank-shaft fitted with two cranks *e c*, *f d*, *carrying* a crank-pin *c d*. Close behind the crank,

journals are turned upon the shaft to work in the shaft-bearings. Beneath is shown the form of the crank-pin, which may be secured by cotters passing through the small bosses of the cranks. In some classes of engines it

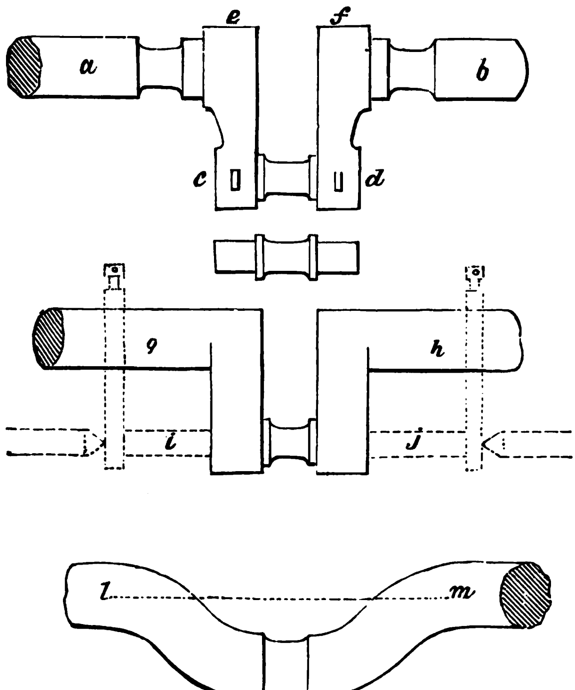


Fig. 89.

is best to *fix* the crank-pin in one crank only, so that in case of any play from wear the cranks may not be strained; this is most likely to occur in marine engines, especially if the framing is not amply stiff. *g i j h* shows a crank-shaft having the crank forged in one piece with it, and *l m*

shows a shaft where the crank is forged on, but with curved arms. This is only used for light work (such as driving an air-pump), as the bearings cannot be brought close enough together to give much steadiness under heavy stress. In making a crank-shaft it is usual to bring it up to a bright surface (except for *black* engines in exposed situations), turning, planing, and filing the different parts according to their forms and positions. For centring

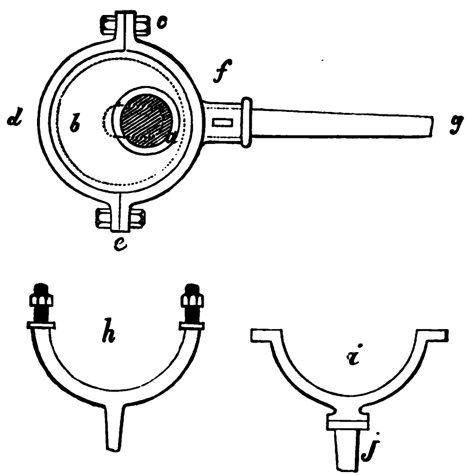


Fig. 90.

the crank-shaft in the lathe, in order to turn the crank-pin when the cranks are formed solid, the arrangement shown at *i j* may be used. The bearings of the crank-shaft are usually of the form already described.

The valves connected with the steam-cylinder are usually worked by EXCENTRICS, of which one is shown at Fig. 90. The excentric is a circular wheel fixed excentrically upon the shaft. *a* is the main shaft to which the excentric is *keyed, b is* the excentric sheave, on the edge of which is

turned a groove to receive a band within which the excentric may revolve. This band corresponds to the cross head of a piston-rod when that is jointed directly to the crank-pin. The band is made in two parts, *c d e* and *e f c*, which are connected by bolts at *c* and *e*. At *f* is a socket to receive the end of the excentric rod, which is firmly cottered therein. This form is generally used with gun-metal straps. Sometimes both sides of the strap are made of the same form as *c d e*, in which case the excentric-rod is forked as shown at *h*. The screwed ends are passed through the bolt-holes at *c* and *e*, and being fitted with nuts, supply at once the means of connecting the two halves of the strap with each other and with the excentric-rod. *i j* shows another form of strap and excentric-rod connection. The excentric-rod may be jointed direct on to the slide-valve rod, or to an arm fixed on a shaft which carries another arm from which the slide-valve is worked.

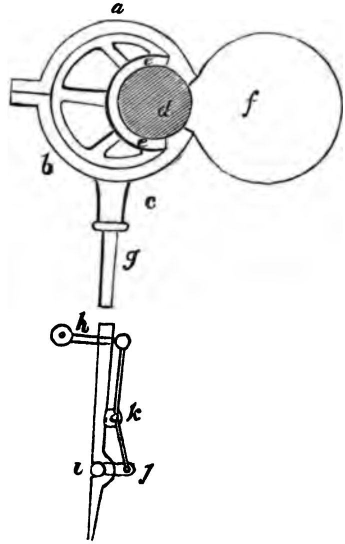


Fig. 91.

As it is necessary that a certain advance be given to the excentric beyond the position of the crank, in order to insure the direction of the engine's motion, some special arrangement must be provided in those engines which occasionally require to be reversed. There are two forms of reversing gear in common use: one generally used in paddle engines, the other for screw-propeller and locomotive engines. Fig. 91

shows the former, which is the ordinary single excentric reversing arrangement. The excentric is not keyed on to the shaft, but so attached that the latter can revolve within it through an angle corresponding to the positions of the excentric for the forward and backward leads, the excentric sheave being balanced in any position by a counterweight *f*, *a b c* being the excentric. Upon the shaft is bolted a segmental collar *e e*, either extremity of which coming in contact with the inner part of the balance-weight *f*, which is bolted to the excentric, will drive the latter. If we suppose the engine to be stopped and the slides moved by hand to such a position as to cause the engine to start in a direction contrary to that in which it was running, the segmental collar *e* will retire from the balance-weight on one side, and having performed a portion of a revolution, will come in contact with it on the other side and cause the excentric then to revolve with the shaft; after which the motion of the engine will continue in that direction until some further alteration is made. It is obviously necessary to provide means whereby the excentric-rod may be temporarily disconnected from the slide-valve gear, so that the latter may be moved by hand to the position necessary to reverse the motion of the engine. The lower part of the excentric-rod is arranged for this purpose. At *i* is a pin attached to an arm on a weigh-shaft actuating the slide-valve; this pin gears in a notch or gab in the excentric-rod, which is also called the GAB-LEVER. Behind this pin the gab-lever is perforated and a strip of metal inserted as shown at *j*. Now if this strip be forced forward it will fill up the notch, forcing the pin out of it and thereby disengaging the valves, nor will the pin *i* be able to re-enter the notch until the strip of metal is withdrawn. The strip of metal is attached to the end *j* of a lever working on a fulcrum *k*; at the upper end of the lever is a handle *h* passing through

the gab-lever. By pushing the handle *h* towards the gab-lever the engine is thrown out of gear; pulling it back allows the engine to fall into gear as the notch of the gab-lever passes over the pin *i*. In some cases the stop is dispensed with, and the gab-lever *raised* from the pin by an arrangement shown at Fig. 92. *a b* is the gab-lever, *c* the pin communicating with the slide-valves, *d* is a short shaft on which is an arm *d e*, carrying at the extremity *e* a small roller close under the gab-lever. To the short shaft is also fixed an arm *d f* having a link, of which a part is shown at *g f*, attached to it. By moving the link *g f* in the direction of the arrow, the gab-lever will be raised clear of the pin *c*.

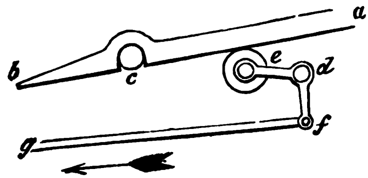


Fig. 92.

In locomotive and some other engines, the crank-shaft carries *two* excentrics keyed on it, one to drive for forward and the other for backward motion of the engine. This arrangement is shown, Fig. 93. *a* is the forward, *b* the backward excentric. The lower extremities of the excentric-rods are attached to the ends of a slotted link *c*, within the slot of which is fitted a block connected with the slide-rod *e*. At the back of the link and in one piece with it is an eye *f*, from which a link proceeds to the end *d* of an arm carried on a shaft *g*, which has also an arm *g h*, and to the extremity *h* is attached a link as shown. By moving this link in the direction of the arrow, the link *c* will be raised, and sliding over the block attached to the slide-rod *e*, the valves will be brought under the control of the excentric *b*; by a reverse movement the valves will be brought under the control of the excentric *a*. The block need not be quite at the end of the link, and by its position

the point of "cut off" can be regulated. Sometimes the link *c* is suspended from a fixed point, and the block *e* put

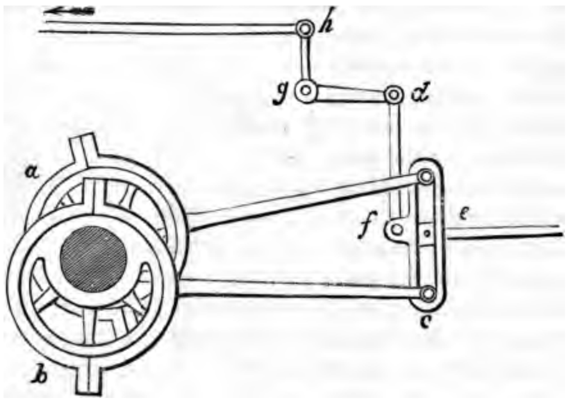


Fig. 93.

on the end of a link jointed to the slide-rod, in which case the block *e* is raised or lowered instead of the link *c*.

When separate expansion-valves are used, they are usually actuated by CAMS fixed on the crank-shaft, as shown at Fig. 94; the several cams being placed side by side to give different degrees of expansion. *a* is the main shaft, *b* the boss carrying the various cambers *c c c c* and *d d d d*; *e* is a roller which can be moved on its axis so as to rest against any cam as may be required; it is carried at the end of an arm fixed to a short shaft *f*. The roller will twice during each revolution, that is, once in every stroke of the engine, be forced back by the cam, whereby the link *g h* will be raised and the expansion-valve closed. Of course in making a change the roller *e* must be shifted; when resting on the plain part of the boss, its position is regulated by a *fork i*, worked by turning a shaft having a screw-thread

cut on it. Another view of the expansion-cams is shown at *i*.

In order to render more uniform the motion of mill engines, they are fitted usually with heavy fly-wheels, which, with a small increase of velocity, accumulate the excess of work at one part of the revolution, to be given off at some other when the work is deficient. The fly-wheel is made of cast iron entirely, or has a cast-iron rim carried on wrought-iron arms which are laid in the sand of the mould, and so have their ends cast into the boss and rim of the wheel. The fly-wheel must be very securely keyed on to the shaft. It is sometimes made as a toothed wheel to drive machinery; but the driver is usually a separate wheel or drum. The proportions of the fly-wheel may be determined from the following formulæ, which are taken from Moseley's elaborate investigation of the principles of its action.

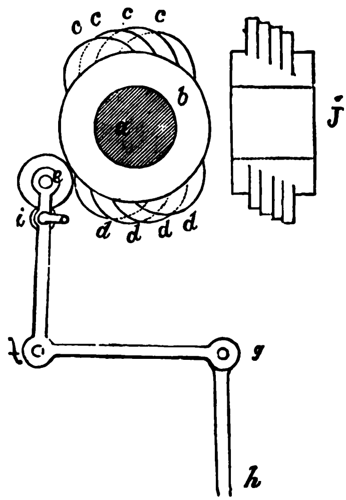


Fig. 94.

Let W = weight in tons; H = horse-power of engine; N = twice the number of revolutions per minute (that is, the number of strokes); R = mean radius; K = section of cast-iron rim in square feet; $\frac{1}{n}$ = the greatest variation in

from mean speed allowed. Then for a single-acting engine:—

$$W = 95274 \frac{H\,n}{N^3\ R^2}; \ R = \frac{42{\cdot}26}{N} \sqrt[3]{\frac{H\,n}{K}};$$

$$K = 75477 \ \frac{H\,n}{N^3\ R^3}.$$

For a double-acting engine:—

$$W = 18194 \ \frac{H\,n}{N^3\ R^2}; \ R = \frac{23{\cdot}34}{N} \sqrt[3]{\frac{H\,n}{K}};$$

$$K = 14414 \frac{H\,n}{N^3\ R^2}.$$

For a two-cylinder double-cranked engine:—

$$W = 9097 \ \frac{H\,n}{N^3\ R^2}; \ R = \frac{19{\cdot}32}{N} \sqrt[3]{\frac{H\,n}{K}};$$

$$K = 7207 \ \frac{H\,n}{N^3\ R^3}.$$

I will take an example from the last-named class of engine:—

Let $H = 100$; $N = 60$; $R = 7$; and $\frac{1}{n} = \frac{1}{10}$, that is, the velocity is never to vary more than one-tenth of the mean velocity; then

$$W = 9097 \times \frac{100 \times 10}{(60)^3 \times (7)^2} = 0{\cdot}86 \text{ tons} = 1926 \text{ lbs.}$$

The common governor used to regulate the admission of steam to the valve-chest has already been described at page 83. There are many forms now in use, but I have not space for their enumeration, and that already explained *is the most* generally used.

A common form of condenser is shown at Fig. 95. The steam is condensed by a jet of water scattered by a rose.

Surface condensers consist of tubes passing through the condenser, through which water is circulated, so that the

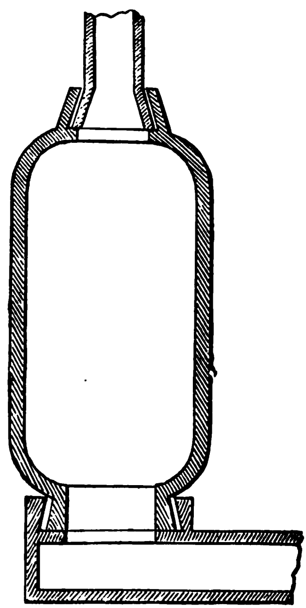


Fig. 95.

steam is condensed by contact with the cold metal tubes, and not by direct contact with the condensation water.

CHAPTER X.

TYPICAL FORMS OF STEAM-ENGINES

IN this chapter I purpose describing the typical arrangements of the various elements of the steam-engine in their simplest forms, commencing with the BEAM-ENGINE, of which a side elevation is shown in Fig. 96. *a* is the steam

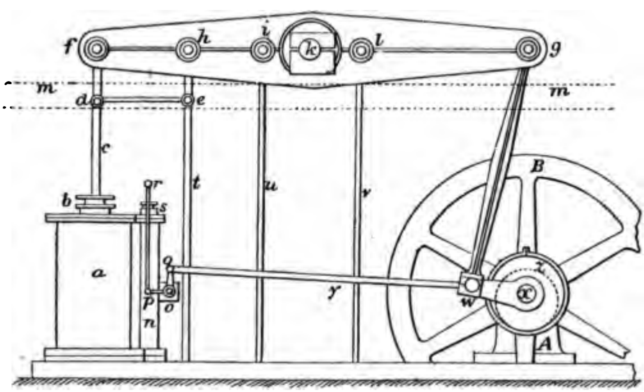


Fig. 96.

cylinder, *b* the stuffing-box and gland, through which passes the piston-rod *c*, attached at its upper end to the link *df*, of which the end *f* is carried on a gudgeon in the beam *fg*. This beam is in two pieces, of which *fg* is one, the various rods being carried between the two halves of the *beam by* gudgeons passing through and keyed into both.

The cross-head *d* of the piston-rod carries one end of a link *d e*, which at *e* joints with another link running back to a fixed centre, or "dead" centre, at *d* (carried by a bracket fixed on the beam shown by the dotted lines *m m*), so as to form a parallel motion for the piston-rod head; the same joint at *e* also connects with the link *e h*, carried at *h* on a gudgeon fixed to the main beam *fg*. At a suitable point in the link *e h* is a journal carrying the upper end of the air-pump rod *t*, which passing down through the floor actuates the air-pump for maintaining the vacuum in the condenser. (The air-pump will be described fully in Chapter XI.) The main beam *fg*, formed as I have indicated above of two parallel plates connected with each other by transverse bars, which also form gudgeons for the dependent rods and links, is carried on the central gudgeon *k* in massive bearings sustained in plummer-blocks, resting upon beams shown by the dotted lines *m m*, these beams being fixed in the walls of the engine-house. The gudgeon *i* carries the rod *u* actuating the cold-water pump, by which water is raised into the tank containing the condenser and air-pump. The gudgeon *l* carries the feed, or hot-water pump rod *v*, this pump supplying the boiler from the hot water drawn from the condenser by the air-pump. At the end *g* of the main beam is attached the connecting-rod *g w*, which through the crank *w x* actuates the main shaft *x* carrying the fly-wheel B, and being itself carried in bearings supported by the pedestal A. Upon the main shaft *x* is keyed the excentric *z*, from which the excentric rod *y* passes to the end *q* of an arm *q o*, keyed on to a rocking shaft *o*, upon which are two parallel arms *o p* having their ends *p* jointed to the lower ends of links *p r*, at the top of which (*r*) is a cross-head carrying the slide-valve rod, which, passing through the gland and stuffing-box *s*, actuates the slide valve contained in the valve jacket *n*.

The CORNISH PUMPING ENGINE is a beam-engine, but

instead of the connecting-rod *g w*, the pump-rod is attached to the end *g* of the main beam. These engines are single acting, that is, the steam acts only on the top side of the piston, thus making what is called the "*indoor stroke*," the return stroke being made by a heavy weight on the pump-rod called the preponderating weight. The action of the engine then is as follows:—The steam entering the top of the cylinder forces down the piston, lifting the preponderating weight, and drawing water into the pump-barrel; communication is then made between the top and bottom of the cylinder, through the equilibrium-valve, when the preponderating weight being free to act presses the pump plunger down, forcing the water to the required elevation. Engines of this description frequently have a steam jacket around the cylinder to prevent loss of heat by radiation during the stroke. Such an addition is shown in part vertical section in Fig. 97.

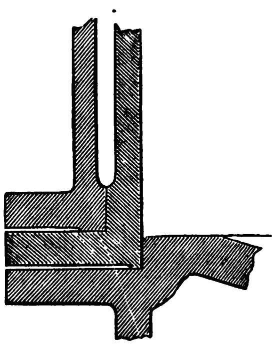


Fig. 97.

The lower end of the cylinder, after the down or "*outdoor stroke*" of the pump-rod, is put into communication with the condenser. The steam-valves in this type of engine are all separate; there is the "steam-valve," the "equilibrium-valve," and the "exhaust-valve," worked by arms on separate weigh shafts. These valves are opened by weights which come into action on the release of certain catches, the valves being closed by stops on a "plug-rod" attached to the parallel motion. The catches are of the [illegible] shown in Fig. 98. *a b* and *c* are the three weigh [illegible] are attached quadrants as shown, fixed to

the ends of the shafts. When the valve handles are acted on by the stops or tappets, the shafts revolve until the quadrants assume the positions shown by the full lines in the figure, where they are retained by pins attached to levers moving upon the fulcra *x x x* and equilibrated by weights *w w w*. When the catches are raised the balance levers cause the quadrants to pass to the positions shown by the dotted lines, opening the valves at the same time. The catches are raised by "CATARACTS," which consist of pumps having a free inlet valve, but a small and adjustable outlet which regulates the time of descent of the piston, which piston is pressed down by a weight on its rod; the piston is raised at each stroke of the engine by a stop on the plug-rod. Sometimes the quadrants are so arranged as to interact, the cataract being dispensed with.

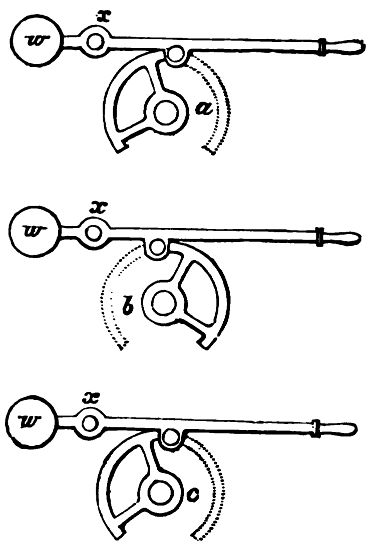


Fig. 98.

The economy of the Cornish engine is very great, and that machine as perfected by the late Mr. Thomas Wicksteed (through whose indomitable energy that type of engine was introduced into the London and other Waterworks), performed on a three years' trial 109,000,000 foot-lbs. per 112 lbs. of Newcastle coal consumed. Higher duties have been reported from Cornwall, but those are

inaccurate, as in some cases the loss of water through the pump valves amounted to 16 per cent. and more. The first Cornish engine erected in London (at the West Ham, now the East London Waterworks), performed when improved by Wicksteed, 103,000,000 foot-lbs. per 112 lbs. of coal, and the 109,000,000 foot-lbs. duty was performed by the Wicksteed engine subsequently erected at the same Works, and which engine has been the prototype for the

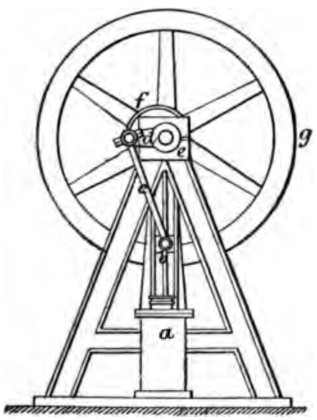


Fig. 99.

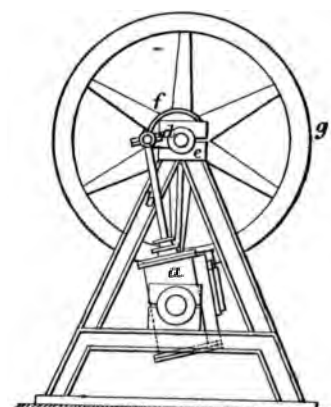


Fig. 100.

large pumping engines at the Leeds Water-works and elsewhere.

Fig. 99 is an elevation of a vertical engine, carried upon a frame. *a* is the cylinder; *b* the piston-rod, of which the head is steadied by guides; *c* is the connecting-rod working the crank *d*, which is keyed on the main shaft, carried in bearings in the plummer-block *e*; *f* is the excentric by which the slide-valve is worked, and *g* the fly-wheel.

Fig. 100 is an elevation of a vertical oscillating engine. *a* is the cylinder, *b* the piston-rod, connected directly to the

crank *d*, actuating the main shaft carried in the bearings *e*; *f* is the slide-valve excentric, and *g* the fly-wheel.

In the horizontal engine the general arrangement is the same as in the vertical engine illustrated in Fig. 99, but the cylinder lies horizontally upon a bed-plate, which also serves as a foundation for the main shaft and other parts of the engine.

Stationary engines are usually regulated by a governor, the action of which determines the supply of steam to the cylinder. The simplest form of governor is shown in Fig 101. Upon the vertical shaft *a a* are suspended a pair of conical pendulums *b b*, carried by the rods *b c*, *b c*, to which are jointed at *d d* the links *d e*, *d e*, the lower ends *e e* being connected with the collar shown, which is able to slide vertically upon the shaft *a a*; in a groove in this collar a pin *f* rests, and by the vertical movement of the collar this pin is raised or lowered, and, vibrating about the centre *g*, actuates the steam-valve by the rod *g h*.

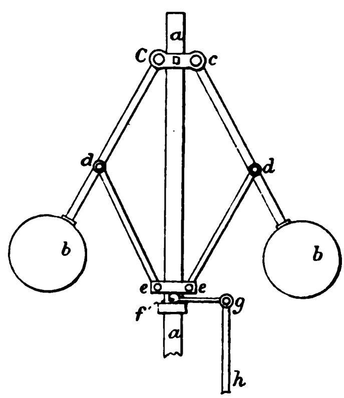


Fig. 101.

From these typical forms are derived all the steam-engines commonly used, the positions of the cylinders being varied to suit the purposes for which the engines are required.

The most compact form in which the steam-engine occurs is that of the locomotive, which is illustrated in Figs. 102 and 103, the first being a longitudinal section and the second the plan of an express passenger engine.

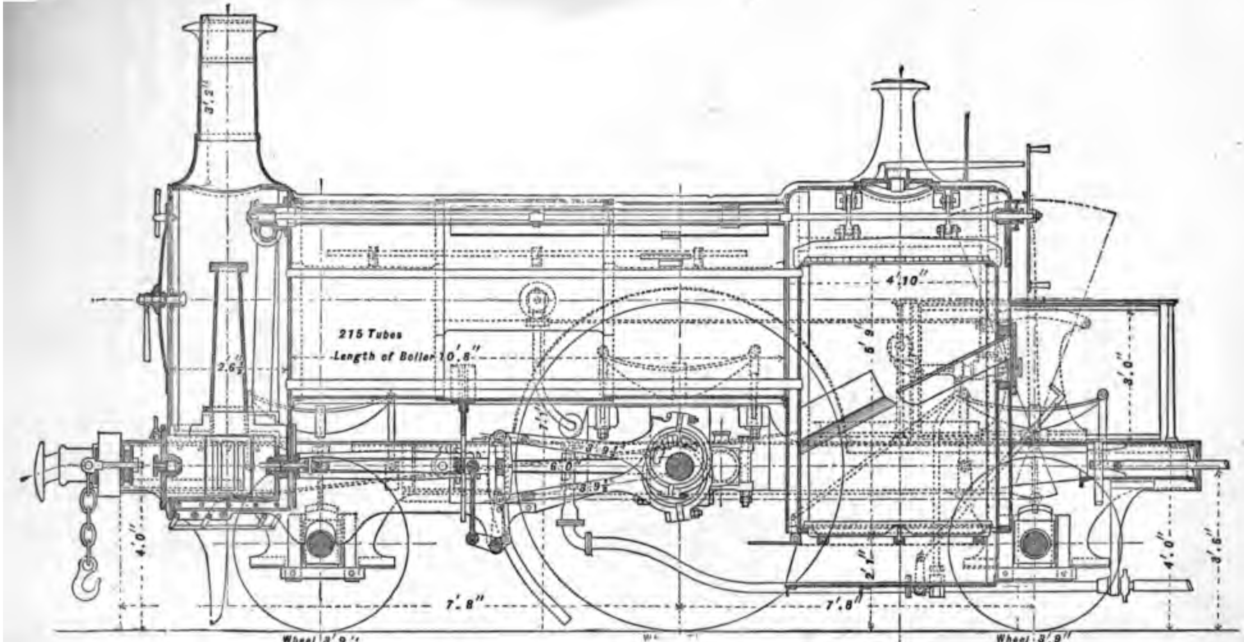
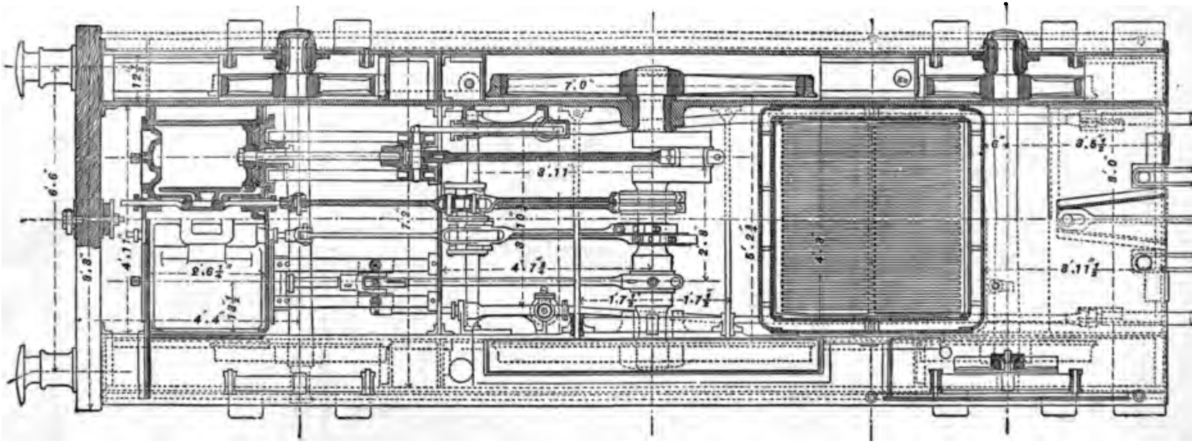

3' 2"
215 Tubes
Length of Boiler 10' 8"
2' 6½"
4' 10"
5' 9"
3' 0"
4' 0"
3' 6"
7' 8"
7' 8"
2' 1"
6' 0"
Wheel 3' 9"
Wheel 3' 9"

Fig. 100



7.0"
12½"
6.6"
9.8"
4.11"
2.6¼"
4.4"
13½"
8.11"
7.2"
8.10½"
4.7½"
2.8"
1.7½"
1.7½"
5.2½"
4.3"
6"
3.5½"
9.0"
3.11½"

Fig. 103.

A great number of designs for ROTARY ENGINES have been patented at various times, but none of these have given sufficient satisfaction to lead to the supersession of the rotative engines as generally constructed.

There are certain mechanical defects in the rotary engines which outweigh their advantages of lightness, simplicity, &c., and notably the difficulty of keeping the pistons steam-tight; but to enter into this part of the subject in detail would occupy more space than I have at my disposal, and although interesting, this subject is not practically profitable.

CHAPTER XI.

PUMPS, INJECTORS, EJECTORS, VALVES, AND CONDENSERS.

BEFORE describing the principles and construction of pumps I must explain the duty of an ordinary automatic VALVE. An ordinary valve consists of a plate with an aperture in it, such aperture being covered by a plate capable of opening in one direction. This valve may be a flap hinged to the perforated plate, such as are shown at *b*, *d*, and *e*, in sections A and B, Fig. 104; or it may be a rising plate steadied by a stalk, as shown at *b* and *e*, section C; and in top and bottom plan at D and E, the three-edged stalk steadies the valve but allows the passage of liquids or fluids through the concave parts of the stalk. A valve may also be formed by a ball falling into a spherical seat surrounding the aperture to be closed, or by an elastic band surrounding a perforated pipe, which band expands to allow the exit of liquid or fluid, but prevents its return through the perforations. There are innumerable kinds of valves, but enough have been mentioned for my present purpose, it being borne in mind that the particular property of the valves under discussion is, that they permit the flow of liquids or fluids *in one direction only*, preventing their return by the same passage. The rise of the valve is limited by a guard.

A, Fig. 104, is a vertical section of a common LIFT-PUMP. *a* is a pipe rising from a well or other source of supply, guarded at the top by the CLACK-VALVE *b*; above this is a

properly bored cylinder or pump-barrel, in which moves water-tight the piston or plunger *c*, having an aperture guarded by the clack-valve *d*. Both these valves open upwards, so that the liquid can pass up through them, but cannot return. The plunger or bucket *c* is attached to the forked end *e* of the pump-rod *f*, *g* is the head of the pump. The action is as follows:—Suppose the pump-bucket to be

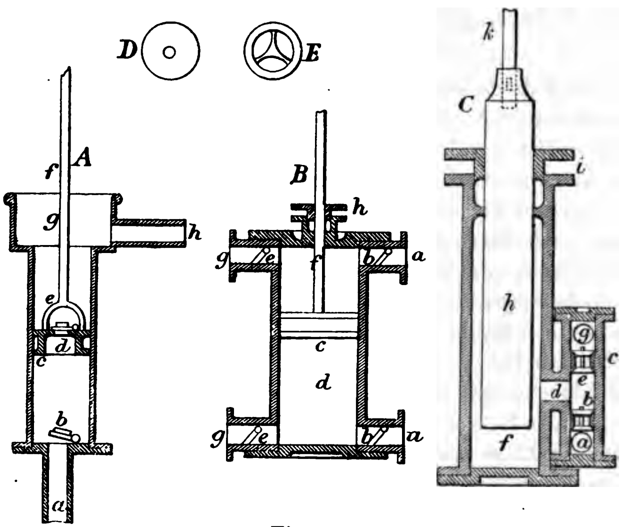


Fig. 104.

at the bottom of the barrel, then on raising it a partial vacuum will be left beneath it, as the air cannot pass down through the valve *d* or past the packing by which the bucket is made to fit the barrel, hence the atmospheric pressure on the surface of the water in the well, being unbalanced by an equal pressure in the pump-barrel, forces water up through the valve *b* into the pump-barrel, where *it is retained* by the valve *b*; on making a down stroke of

the pump-bucket the valve *d* opens and the water passes through as the bucket descends, and on the next up stroke, the valve *d* closing, this water is lifted into the head or cistern *g*, whence it flows away through the pipe *h*. At the same time more water rises through *b* into the pump-barrel. The height of lift of this pump is limited by that of a column of water which the atmospheric pressure will support, and by the workmanship of the valves, barrel, and bucket; the last is fitted with leather or metal packings.

The pressure of the atmosphere being called 15 lbs. per square inch, the column of water it will sustain will be one square inch in area and of such height as to weigh 15 lbs. Water weighs 62.5 lbs. per cubic foot, therefore a column one inch square and one foot high weighs $\frac{62 \cdot 5}{144} = 0 \cdot 434$ lbs., hence the column balanced by the atmosphere will be $\frac{15}{0 \cdot 434} = 34 \cdot 5$ feet; but a pump cannot work at this height, for in addition to the water there is the weight of the valve to lift and friction in the pipes to overcome; besides, the vacuum in the pump-barrel can never be perfect, as there is always *air in water*, which comes out when the atmospheric pressure is removed from the surface, and altogether 28 feet may be regarded as a good height for the pump to work at. The force (in addition to that required to overcome the friction of the pump and the valve-lifting) required to raise the plunger will be equal to the weight of a column of water equal in diameter to the pump-bucket, and in height to the distance from the surface of the water to the underside of the pump-bucket, hence as the bucket rises an increasing force is required, the mean being that corresponding to the position of the bucket at half stroke. Let P = force in lbs.; d =

diameter of bucket in inches; $h =$ lift of water in feet; then

$$P = \cdot 7854\ d^2 \times h \times \cdot 434 \text{ lbs.} = \cdot 342\ d^2 h.$$

B is a vertical section of a double-acting FORCE-PUMP. *d* is the barrel, fitted with a solid piston *c*, properly packed to fit the barrel; the piston-rod *f* works through the stuffing-box *h*. *a a* are inlets guarded by valves *b b*, opening inwards, and *g g* are outlets guarded by valves *e e*, opening outwards. When the piston moves downwards fluid enters the barrel through *b* at the top, and that below the piston is expelled at the bottom through *e*; on the ascent of the piston a contrary action occurs. When this pump is used for water the force necessary to work it will be found by the above formula, but making $h =$ the height in feet from the surface of the water at the supply to the level to which it is forced, to which height there is no limit but in the strength of the machinery. When the pump is used for air the force to work it will be the pressure of air per square inch multiplied by the area of the piston.

A form of pump very generally used for forcing water, and known as the PLUNGER-PUMP, is shown in vertical section at C. *f* is the pump-barrel within which moves the plunger *h*, working water-tight through the stuffing-box *i*. Into the upper end of the plunger is securely cottered the pump-rod *k*; *c* is the valve-box communicating by the passage *d* with the pump-barrel; *a* is the inlet whence the water passes through the stalk valve *b* into the barrel during the ascent of the plunger. On the descent of the plunger the water is forced out of the barrel through the passage *d* and the stalk-valve *e* into the delivery pipe *g*.

Very large pumps are made on the plunger principle up to diameters of 50 inches, with as much as 11 feet stroke; the plungers are then cast hollow. In order that *the plunger may* work as easily as possible in the stuffing-

box, it should after being turned be "draw-filed," that is, the file being held transversely to the length of the plunger, is drawn in the direction of the plunger's length, so that the minute grooves around the plunger left by the turning tool are filed off, and if any such grooves exist on the finished work, they are longitudinal, that is to say, in the direction of motion. The quantity of water forced at each stroke will be equal to the area of the plunger bottom multiplied by the length of stroke; and as 6·25 gallons equal a cubic foot, if $d =$ diameter of plunger in inches, $l =$ stroke in feet, and q quantity of water discharged per stroke, in gallons,

$$q = 6{\cdot}25 \times \frac{{\cdot}7854\ d^2}{144} \times l = {\cdot}034\ d^2\ l.$$

Thus in the case of the large plunger above alluded to, the discharge would be—

$$q = {\cdot}034 \times 50^2 \times 11 = 935 \text{ gallons per stroke.}$$

The water was raised 102 feet, hence the nett work done per stroke was

935 gallons $\times$ 10 lbs. per gallon $\times$ 100 feet $=$ 935000 foot-lbs. per stroke.

This pump was worked by a single-acting Cornish engine, the plunger and its load or preponderating weight being lifted by the steam stroke, the down stroke being made by the preponderating weight. The preponderating weight is thus determined. That part of it required to overcome the friction of the engine is determined by direct experiment, the part necessary to raise the water is to be calculated; thus in the present case the height of lift being 100 feet from *mid-stroke* of the plunger, the pressure of the column of water on the plunger bottom would be ·434 $\times$ 100 $=$ 43·4 lbs. per square inch, and the plunger having an area $= {\cdot}7854\ d^2 = {\cdot}7854 \times 50^2 = 1963{\cdot}5$ square inches, the total upward mean pressure of the water against the plunger will be $1963{\cdot}5 \times 43{\cdot}4 = 85215{\cdot}9$ lbs., which must

be balanced by a corresponding quantity of preponderating weight on the pump rod: this amounts to 38 tons, without the weight requisite to overcome the engine friction and work the air-pumps, feed-pumps, &c.

Pumps of such magnitude require valves of special form, for it may easily be imagined how great a concussion would be produced on the valve-seat by an ordinary clack-valve, say 2 feet in diameter, falling upon its seat with the pressure of 100 feet of water on the top of it. To avoid this a valve is required which will fall rapidly and reach its seat before the column of water commences to return. Such a valve is the DOUBLE-BEAT VALVE, shown in vertical section in Fig. 105. It has two seats, as shown, and when open the water passes through in the directions indicated by the arrows *a a* and *b b*. The valve is steadied by inside ribs and a central spindle; under the collar of the latter is fixed a leather washer to prevent concussion when the valve opens. The surface of the valve acting upon the water, or acted on by it, is the annular surface comprised between the two valve-seats, hence in proportion to the valve area a much greater pressure is exerted to overcome the resistance of the water than in a common valve. Several other forms of valves have been used for the same purpose, but I have not space for their description. All metal valves must be truly fitted, by surfacing or otherwise, to their seats.

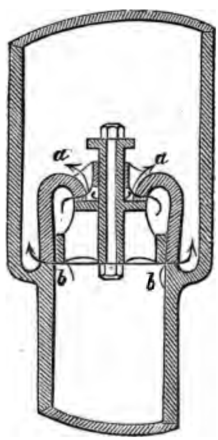


Fig. 105.

It is evident that for the proper effect of a valve to be *obtained,* its rise should be such that the water-way be-

tween the seating and the edge of the valve is not less than the area of the valve aperture. For a circular valve the area will be $=3{\cdot}1416\,r^2$, where $r=$ radius, and if $h=$ height of lift, the waterway between the valve and its seating $=6{\cdot}2832\ r\,h$; hence the proper rise is $h=\frac{r}{2}$.

In the double-beat valve let $r=$ the less, and $r'=$ the greater diameter of the valve-seats, then the effective area of the valve is $=3{\cdot}1416\ r'^2$, and the area of waterway given by the rise of the valve is $=6{\cdot}2832\,h\,(r+r')$, therefore

$$h=\frac{r'^2}{2\,(r+r')}.$$

I may observe that if $r=r'$, the valve is not affected by

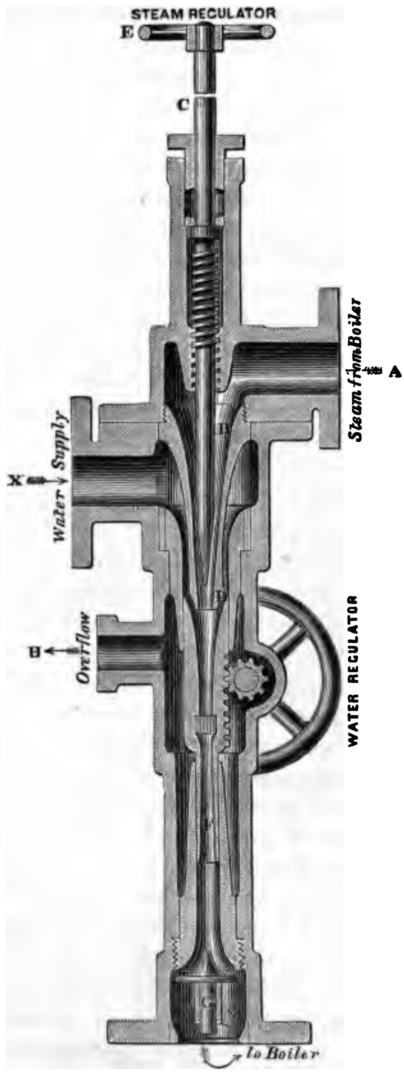


Fig. 106.

any difference of pressure above and below it; it is then called an EQUILIBRIUM-VALVE, and as such is used in the Cornish engine to regulate the ingress and egress of steam to and from the cylinder. The nearer the value of r approaches to that of r', the greater will be the pressure per square inch required to open the valve.

For many years past the ordinary pump has for some purposes, such as supplying the feed-water to locomotive and other boilers, been displaced by the INJECTOR, a most ingenious apparatus illustrated in section in Fig. 106.

It will be observed that in this arrangement the steam leaving the boiler passes through the injector, and re-enters the same boiler, carrying with it a quantity of water. At first sight it may seem curious that the steam propelled only by the boiler pressure, can again re-enter the same boiler, even without carrying any water with it; but I think the action may be explained as follows.

Suppose the area of the pipe leaving the boiler to be one square inch, the steam in that pipe will move with a velocity proportional to the pressure behind it, say 100 lbs. on the square inch; as the steam passes forward to that part where the cooling action of the feed-water can be felt, it is partially condensed, and therefore its sectional area is reduced, and there being the same *weight* of matter moving at the same velocity, we have the 100 lbs. pressure on *less than a square inch*, therefore the momentum of this partially condensed stream of steam is sufficient to overcome the resistance of the steam in the boiler and to carry in with it a supply of feed-water.

The action of the injector must not be confounded with that of the EJECTOR, the latter being used to exhaust the condenser or other vessel of air or other gas as may be required. This apparatus I will explain by a reference to Fig. 108, in which a current of steam passing from the *passage* $a\ a$ around the nozzle c into the tube b, draws

through that nozzle air through the apertures *d d d*. The figure shows a vertical section of the ejectors used in connection with an atmospheric brake, subsequently to be described. Now the annular stream of steam rushing *past* the aperture of the nozzle *c* carries with it the air in the centre of such annular stream, thus creating a partial vacuum in the passages *d d*.

The first important application of the ejector appeared in Alexander Morton's Ejector Condenser, in which for the first time the air-pump was superseded by an ejector.

The common condenser consists of a vessel into which a water-spray is thrown through a perforated rose, and the steam passing from the cylinder into the condenser, coming in contact with this spray, resumes its liquid condition.

Another form of the same apparatus is that known as the SURFACE CONDENSER. In this the condensing medium does not come into direct contact with the steam to be condensed, the latter passes into an aggregation of tubes, around which the condensing medium circulates. Generally in surface condensers water is used for the purpose of condensation, but I am informed that a Leeds manufacturer has recently proposed to adapt to steam tramcars the AIR SURFACE CONDENSER invented by Mr. Craddock about twenty-five years since. The efficiency of a condenser is measured by the vacuum obtained, and I think it advisable here to explain the vacuum gauge as compared with the steam gauge.

In speaking of steam pressure we say, for instance, 50 *pounds* per square inch; in speaking of vacuum we say, for instance, 25 *inches*. In the former case the meaning is evident to the merest tyro; in the latter it must be explained that the 25 inches of vacuum means that the pressure in the vessel in which this vacuum exists is less than the atmospheric pressure by a quantity sufficient to support a column of mercury 25 inches high: thus, if the pressure of

the atmosphere were 30¼ inches of mercury and the vacuum 27 inches of mercury, there would be an *absolute pressure* in the condenser of 3¼ inches of mercury, or 1·596 lbs. per square inch, the weight of one cubic inch of mercury being 0·491 lbs.

When air-pumps of the ordinary construction are used, it is evidently necessary to make the valves as light, or as easily opened, as possible; for this purpose india-rubber valves closing upon gratings are frequently used, and where metal valves are employed they should be hung nearly vertically, so as to open under a very slight pressure, otherwise a good vacuum cannot be obtained.

Surface condensers cooled by water require circulating pumps to keep the condensing water in motion; in one form of Mr. Craddock's air surface condenser, the necessary circulation of air was maintained by causing the condenser (formed of tubes) to revolve rapidly, thus by centrifugal action causing a current of air from the axis to the periphery of the apparatus.

CHAPTER XII.

BOILERS AND THEIR FURNACES.

THE design and arrangement of the boiler and furnace demand the same careful consideration as the engine, and, in fact, there are numerically more points to be determined, for whatever engine we use still the *steam is the same*, but in different localities and under different circumstances the boilers must be worked with *different fuels*.

Proceeding to determine the proportions of boilers, I will first consider the relation of heating surface to grate surface and fuel consumed. The heating surface is the metallic area which is on one side in contact with the water, and on the other exposed to the flame or hot gases from the furnace. To secure equal evaporative efficiency:—

1. If the grate furnace is constant, the quantity of fuel consumed per hour should vary as the square of the heating surface.

2. If the heating surface is constant, the quantity of fuel should vary inversely as the grate surface.

3. If the consumption of fuel is constant, the quantity of fuel should vary as the square of the heating surface.

If C represents a constant depending on the type of boiler used, then these three laws will be embodied in the formula,—

$$Q = C \times \frac{h^2}{a} \qquad (1)$$

where Q = pounds of fuel per hour, h = area of heating surface, and a = area of grate surface.

Some characteristic types of boilers are illustrated on Plate IV. A is a longitudinal, and B a cross section of an ordinary CORNISH BOILER, consisting of a cylindrical shell enclosing a tube in which is placed the furnace. At *a* are fire-bars forming the grate, from whence the flames and hot air pass over the fire-bridge *h* along the flue *b*, thence the heated gases are conducted through flues passing outside the shell, and ultimately enter the chimney shaft. *c c*, is the shell of the boiler, *d* and *e* the front and back ends, attached to the outer shell by the angle irons *f f*, and to the internal flue by the angle irons *g g*. Sometimes the end plates are flanged round the edges to obviate the necessity of using angle irons there. *i* is the furnace door through which the fuel is introduced.

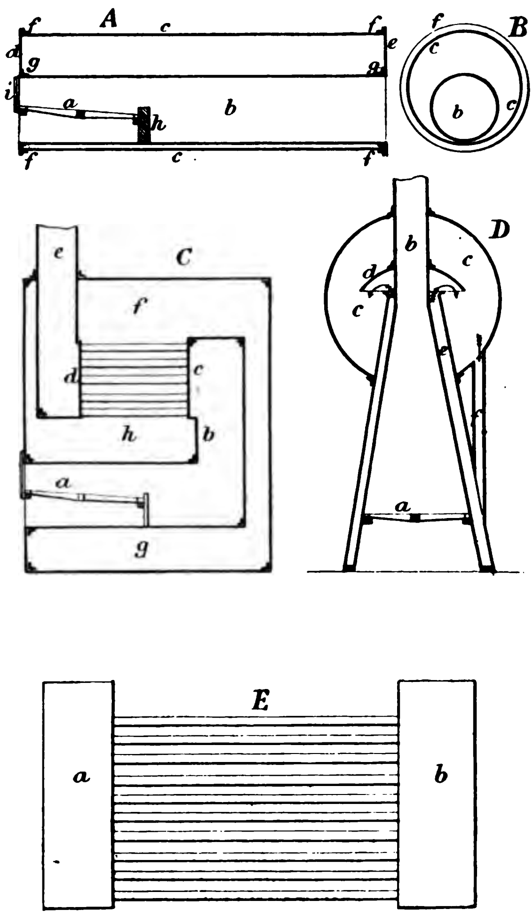
The MANCHESTER BOILER differs from the Cornish in having two flue tubes instead of one, these being placed side by side. Sometimes tubes are placed across the flues to afford further heating surface, the water flowing freely into and through such tubes.

Boilers in which small tubes are used are divided into two principal classes, TUBULAR BOILERS and TUBULOUS BOILERS; in the former the heated gases from the furnace pass *through* tubes surrounded by water, in the latter those heated gases pass *around* tubes containing water. In marine boilers the heated gases cannot be carried in flues *outside* the boiler, hence all the heating surface must be obtained within the shell of the boiler.

C, Plate IV., is a longitudinal section of a MARINE TUBULAR BOILER: *a* is the grate, whence the flames and hot gases pass into the chamber *b*, and outward through the tubes fixed to the tube plates *c* and *d*, into the uptake *e*, which terminates at the base of the funnel. *f* is the steam space, and *g* and *h* the lower parts of the boiler, occupied by water.

D is a vertical section of a most ingenious boiler,

PLATE IV.



To face page 168.

designed by Mr. William Whittle, of Smethwick, near Birmingham, and is called the STAFFORDSHIRE BOILER. *a* is the fire-grate contained in a truncated cone joining the base of the chimney *b*. This conical part is surrounded by another, so as to enclose a water space *e*, opening at the top into the body, *c c*, of the boiler. The intense heat of the furnace causes a rapid rush of steam and water carried with it up the water space *e*, and to prevent priming, there is at the outlet of this water space a deflecting plate *d*, and the space left vacant in *e* is instantly filled by water flowing from the body, *c c*, down the pipe *f*, so that however quick the evaporation, there can be no danger of burning the plates surrounding the furnace, so long as the boiler is properly supplied with feed water.

E is a form of tubulous boiler, consisting of two vessels *a* and *b*, connected by small tubes in which the water circulates under the action of heat. The boiler is enclosed in masonry which carries the furnace bars, the flame and heated gases pass amongst the tubes, and thence into the flues and chimney.

The locomotive tubular boiler is illustrated in Chapter X.

A Cornish boiler will burn from 6 to 10 lbs. of fuel per square foot of grate surface per hour; hence taking the average duty of Cornish engines at 80,000,000 foot-lbs. per 112 lbs. of coal, the rule for grate surface will be as follows:—Let the average consumption of coal be 8 lbs. per square foot of grate per hour, H P = horse-power, G = area of grate in square feet, then—

$$G = \frac{H\,P}{3} \text{ (nearly).}$$

The proper heating surface = S would be, if taken as *all horizontal*,

$$S = 8 \cdot 5 \times H\,P.$$

Vertical heating surface has only half the efficiency of

horizontal heating surface, assuming that such horizontal surface is *above* the flame or heated gas; hence all vertical surface taken in the total quantity determined by the above formula must be doubled. Comparing the two formulæ, the ratio of heating surface to grate surface in the Cornish boiler is found to be—

$$\frac{S}{G} = \frac{8 \cdot 5 \times HP}{\frac{HP}{3}} = 8 \cdot 5 \times 3 = 25 \cdot 5.$$

In practice it will be sufficiently accurate to make the heating surface 26 times the area of the grate surface.

In the equation (1) the value of C for Cornish boilers will be—

$$C = \frac{Q \times a}{h^2} = \frac{3 \times 1}{676} = 0 \cdot 0118.$$

An ordinary factory boiler will burn about 15 lbs. of coal per square foot of grate surface per hour: hence if the engine is working with a consumption of 5 lbs. of coal per horse-power per hour, the grate surface will be in the same proportion as above, and also the heating surface; but if an engine (compound, for instance) be working at a consumption of 3 lbs. of coal per horse-power per hour—

$$G = \frac{HP}{5}$$

and,

$$S = 8 \cdot 5 \times HP \therefore \frac{S}{G} = \frac{8 \cdot 5 \times HP}{\frac{HP}{5}} = 8 \cdot 5 \times 5 =$$

$$42 \cdot 5 = \text{(say) } 43.$$

Hence the value of C for such boilers will be—

$$C = \frac{Q \times a}{h^2} = \frac{15 \times 1}{1849} = 0 \cdot 0081.$$

In locomotive furnaces the greatest quantity of fuel is

consumed per square foot of grate surface per hour, varying from 40 lbs. to upwards of 100 lbs.; this rapid combustion being due to the strong draught caused by the blast, the waste steam discharged into the chimney acting as an ejector, and so drawing a strong current of air through the furnace, and the tubes leading from the fire-box, to the smoke-box upon which the chimney is mounted. The range being so wide it would be useless to give a special formula for grate surface, but the following general rule may be found useful:—Let F = consumption of fuel per square foot per hour; f = consumption per horse-power per hour; then—

$$G = \frac{HP \times f}{F}.$$

In some high-pressure non-condensing engines the consumption of fuel is very heavy, amounting to 9 or 12 lbs. of coal per horse-power per hour, and this would give a ratio of grate surface to heating surface as 1 to 11. But experience indicates that a mean between this and the ratio for a Cornish boiler will give the most satisfactory results, as regards evaporative efficiency; the mean ratio will be—

$$\frac{26 + 11}{2} = 18{\cdot}5.$$

As to the proper capacity for steam-boilers per horse-power, there has been much conflict of opinion. After many years' experience, Sir William Fairbairn fixed upon 15 to 20 cubic feet as the proper allowance, after deducting the space taken up by flues; but Mr. Robert Armstrong (one of the best authorities on boilers) always maintained that 27 cubic feet per horse-power should be allowed, one-half for water and the other for steam. These quantities will not, of course, apply to tubulous or sectional boilers.

No *general* rule can be laid down for the capacity of

boilers, their forms varying so widely; but it is important to furnish ample steam-room, so that no great fluctuation of boiler pressure shall accrue upon the withdrawal of a cylinder full of steam at each stroke of the engine. The steam also must not be drawn close to the surface of the water in the boiler, otherwise the aqueous particles which are carried with it will cause PRIMING in the cylinder, that is, to use a domestic term, the boiler "boils over" into the cylinder, and unless ample provision is made for the escape of water from the cylinder, serious accidents may occur, for water being *practically* incompressible, if the piston encounter solid water towards the end of its stroke, either the piston or the cylinder-cover *must break*. Marine boilers using salt-water are the most likely to prime, therefore marine-engines are fitted with ample valves to allow the escape of water from the cylinders; these valves are held upon their seats by springs sufficiently strong to prevent the escape of steam, but yielding to the "solid" pressure of the water.

The steam passing from the boiler to the cylinder may be dried by passing it through a SUPER-HEATER, which in its commonest form consists of a collection of pipes around which the steam passes on its way to the cylinder, and through which the hot gases from the furnace pass on their way to the uptake and chimney. There is, though, a disadvantage in using *highly* superheated steam, because it dries and renders inefficient the engine packings.

The general rules for horse-power of boilers may be summarised as follows:—Let H P = horse-power, a = horizontal heating surface in square feet, A = vertical heating surface in square feet, then

$$\mathrm{H\,P} = \frac{a + \frac{\mathrm{A}}{2}}{8{\cdot}5}.$$

Or let $A = \frac{a}{n}$, then $H P = \frac{n \times a + a}{8 \cdot 5 \times n}$.

If, for instance, $a = 100$ feet, and $n = 4$; $H P = \frac{4 \times 100 + 100}{8 \cdot 5 \times 4} = 14 \cdot 7$ horse-power.

TUBULAR BOILERS.—For tubes having half their surfaces exposed to the heat (as in the Cornish and Manchester boilers), let l = length in feet, d = diameter in inches, then $H P = \frac{l\,d}{60}$: for tubes having their entire surface exposed to the heat the formula becomes $H P = \frac{l\,d}{30}$.

We must now consider the proportioning of boilers in regard to strength. Let s = ultimate tensile strength of the iron used for the boiler in lbs. per sectional square inch; t = the thickness of the boiler-shell in inches; p = internal (maximum) pressure of steam in lbs. per square inch; and r = radius in inches, then taking the working strain as $\frac{1}{5}$ the breaking strain, for *solid* work $t = \frac{5\,p\,r}{s}$; for single-riveted work, $t = \frac{10\,p\,r}{s}$; and for double-riveted work $t = \frac{7 \cdot 5\,p\,r}{s}$.

The resistance of wrought-iron tubes to crushing pressure was determined by Mr. William Fairbairn, whose experimental researches in matters connected with engineering science are unequalled both in extent and magnitude, and from his experiments the following formula is deduced. Let t = requisite thickness of metal in flue-tube; l = length in feet of tube; d = diameter of tube in inches, or, if it be elliptical, the diameter fitting the flattest part of the tube; p = the pressure in pounds

per square inch above the atmosphere on the exterior of the tube ; then

$$t = \sqrt{\frac{p\,l\,d}{161200}}.$$

If the tubes be long, they may be virtually divided into shorter ones by fixing in or around them strong angle or T-iron rings.

In boilers having flat sides, such as the common square marine-boiler, and the water-spaces outside the fire-box of a locomotive-engine, it is necessary to use stays in order to prevent the plates from bulging out. The plates in this case are subject to transverse pressure, hence the rule by which to determine their thickness is found from the general laws of the resistance of materials to that kind of strain. Let p = pressure in lbs. per square inch; d = the greatest distance between stays in inches; t = thickness of stayed-plates in inches; then $t = 0{\cdot}008\, d\sqrt{p}$. The stays supporting the plate are subject to tensile strain. Let a = vertical distance between stays in inches, and b the horizontal distance; d = diameter of stays in inches; then $d = \frac{\sqrt{a\,b\,p}}{70}$. If the vertical and horizontal distances are equal, the formula becomes $d = \frac{a}{70}\sqrt{p}$.

The APPENDAGES OF BOILERS are safety-valves, pressure-gauges, feed-pumps or injectors, and gauge-glasses for water-level, and in some cases alarm-whistles to indicate a dangerous fall of water-level, whereby some of the flue-tubes being heated, an explosion or collapse might ensue.

The safety-valve is a valve opening outwards, and loaded to the maximum pressure in lbs. per square inch to which the boiler is designed to work.

The pressure-gauge indicates the pressure per square

inch in the boiler, being actuated by an elastic Bourdon-tube (as used in Kenyon's indicator), or by a corrugated plate like those used in aneroid barometers. The gauge-glass is a glass tube held between two cocks attached to the boiler, the upper in the steam-space, the lower below the water-level, so that the level of water in the boiler can always be observed in the gauge-glass. Feed-pumps are usually of the plunger class, but these are almost displaced by the injector.

The injectors will only work with feed-water under a certain temperature, when lifting. Korting's injectors work at any steam-pressure between 12 lbs. and 150 lbs. per square inch, and if non-lifting, with steam-pressure of 30 lbs. to 75 lbs. per square inch; the temperature of the feed-water may be as high as 145° F. These injectors when lifting the feed-water will work with the latter at a temperature of 140° F. if the lift is under 7 feet. They will lift cold water about 20 feet.

I now pass to the practical construction of boilers—a branch of engineering requiring great care and attention.

Boiler-plates must be of very sound and homogeneous structure, for it is to be remembered that the *weakest part* is the measure of its strength, and moreover, boiler-plates are subjected to certain manipulations, such as bending and flanging, which tend to try the fibrous texture of common merchant iron. Boiler-plates have less tensile strength across the grain than with it; hence in testing such material, samples should be cut in both directions.

While on this subject I will remark on plating-work generally, so as to include tank and girder work; for wrought-iron girders are frequently used to support marine boilers, and the frames of locomotive-engines are invariably of wrought iron. I may here mention in regard to the use of steel for boilers, that I should not adopt that material unless I could secure personal supervision of the

work, its structure being so variable that it is not to be relied upon under a general specification.

We have in boiler-making generally a great advantage over girder-work, inasmuch as the manufacturers cannot very well put in inferior work or materials without being detected, and moreover the makers of engines and boilers seem to take a greater interest and pride in the good quality, both of materials and workmanship, than girder builders, amongst whom a thick coating of paint will cover a multitude of imperfections.

Plates that have to be curved should be bent *before punching or drilling*, and drilled by a radial drilling machine, for if the plates be first punched or drilled, the subsequent bending *distorts the rivet-holes*, and the rivets when set up will not be of the proper form requisite to insure the maximum of strength.

As to the matter of riveting, *per se*, there is not much to be said; there is very little hand-riveting done now, the steam-rivetter having superseded it, and in turn been almost superseded itself by the hydraulic-riveters, which possess such great advantages as to portability and general handiness; and it really is a pleasure to see the quiet, we might say unassuming, way in which one of Tweddle's riveters closes up a rivet with thirty tons pressure noiselessly applied.

One practice which has been only too common must be strongly protested against, and that is the driving up of the snap by which the rivet-head is finished until it cuts into the plate, for such cutting-in destroys a portion of the sectional area of the plate, thus weakening the work; in fact, if there is any collar round the rivet-head it should *not* be cut off.

In regard to punched work, I some eleven years back (in my treatise on "Bridges and Girders," Weale's Series) *recom*mended a practice I then used of punching the holes

smaller than the finished size and clearing out to the full size by a pin-drill, and I have found this method perfectly satisfactory in practice; thus if a $\frac{3}{4}$-inch hole is required it may be punched $\frac{5}{8}$-inch and drilled out to $\frac{3}{4}$-inch diameter; thus the strained portions of the material are removed.

In setting boilers, the seatings must be so arranged that the boilers do not get strained when expanding under the influence of heat; in locomotives the boilers are fixed at one end only, being supported by slides at the fire-box end, otherwise they would hump-up and put a transverse strain on the shells.

In conclusion it may be observed that the safest boilers are those consisting of tubes of small diameter; for not only are they generally much stronger than larger tubes, but if one should burst, such accident will not be attended by the calamitous results accruing from the explosion of a boiler of large diameter.

CHAPTER XIII.

RAILWAY AND TRAMWAY APPLIANCES.

Amongst the most important railway appliances are those designed to insure the security of the passengers and servants of the company; that is, the brake arrangements and the interlocking gear used to prevent the possibility of error in the setting of the signals. I shall first deal with the brake question.

The primary object of the brake is simple enough, being to absorb by friction the accumulated work, or momentum, of the train; but various considerations are involved which really render the subject somewhat intricate. A *perfect* brake should possess the following qualities:—It should be automatic, or self-acting, in case of accident; that is, if the train should separate, the brake ought to put itself on, but in such a way that it can be readily taken off; the retarding effect should not be so sudden as to jerk the passengers; the brake should be perfectly under control of both engine-driver and guards; the brake machinery should be as simple as possible, and so arranged that it cannot be unduly strained by the unequal wear of the brake blocks, which press upon the carriage-wheels.

The best brake is that which will bring a train to rest in the shortest distance, and for that distance take the longest time, and for this reason:—Suppose a train to be running into a station where there is already, on the same line, a train standing; now of two brakes, both capable of bringing a *given train at* a given speed to rest in the same distance,

that which occupies the longer time gives *more time* for the train in front to get out of the way. From this it appears that the retarding effort should rapidly increase from the first imposition of the brake, but experience shows that the wheels should not be skidded or stopped, and the reason is evident; if the wheels are skidded, the surface of friction is only a very narrow band of contact between the wheel and rail, whereas, between the wheel-tire and brake-block there is a large surface, and although the friction of solids is as the pressure regardless of surface, yet practically this does not apply when the surfaces *jump* from each other as the skidded wheel of a railway-carriage jumps from the rail. An arrangement has been patented by which the brake is lifted off the wheel as soon as the latter skids, thus keeping up a fluttering action of the brake calculated to have a "churning" effect upon the passengers.

So soon as the *necessity* of applying continuous brakes to trains became apparent, the Patent Office was flooded with specifications of improvements of various orders; from the *lump of wood* in the vacuum chamber of Mr. Haughton to the refined designs of the accomplished mechanicians who have devoted their abilities to this important subject. I cannot pretend to give even a brief review of all these inventions, and therefore I select for illustration that which appears to me to be the most perfect in its action—Eames's Automatic Vacuum Brake.

The general arrangement of this brake is shown in Fig. 107, the ejectors by which it is attached being illustrated in Fig. 108.

In Fig. 107 the working parts of Eames's brake are shown in vertical section. *a* is the vacuum chamber, closed by the elastic diaphragm *b b*, carrying the metal discs *c c*, bolted together by a nut and bolt terminating in an eye, *d*, to which the link working the brake-lever is attached.

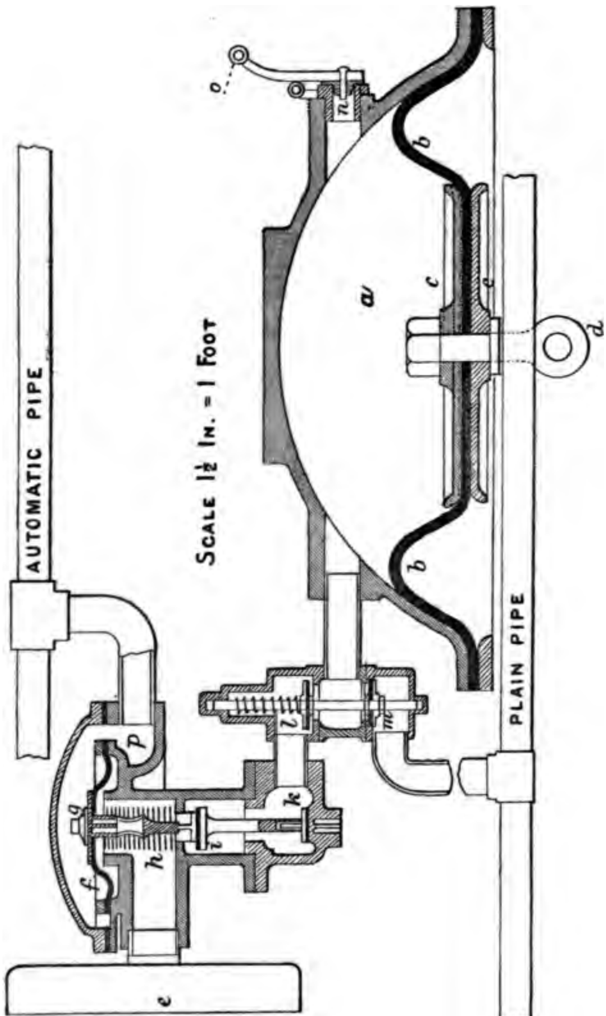


Fig. 107.

In the position shown the brake is on, the diaphragm

being pressed up by the atmosphere, there being a partial vacuum in *a*. *e* is the end of a vacuum vessel attached to each carriage and kept always exhausted by a small ejector, to be described subsequently; there is always maintained (by this ejector) a vacuum in the "automatic pipe" and the vessel *e*. Before the train starts, the small ejector (*e*, Fig. 108) being put in action exhausts the automatic pipe—which with the plain pipe runs the whole length of the train—and through the passage *p*, the space above the elastic diaphragm *f*, drawing that diaphragm upwards and closing the valve *i*, carried on the stem of the discs embracing the diaphragm *f*. This diaphragm having risen, aided by the light-starting spring *h*, the valve *g* opens, and through it the vacuum chamber *e* is exhausted. The valve *i* being closed and its stalk raised, the valve *k* is free to open to the atmospheric pressure; thus letting the valve *l* close by the action of the spiral spring surrounding the spindle to which it and the valve *m* are fixed, the latter (*m*) being then open and the brakes off.

The driver can now put the brakes on by starting the large ejector (*c*, Fig. 108), and so creating a partial vacuum in *a*.

A rupture of the automatic pipe, or the opening of valves connected with it, and under the control of the guards, destroys the vacuum in that pipe, when the valve *g* closes by the atmospheric pressure entering through *p*; then the diaphragm *f* is forced down into the position shown in the figure, opening the valve *i* and closing the valve *k*. A communication being thus made with the vacuum-vessel *e*, the valve *l* is forced open by the air in *a*, which thus becomes partially exhausted, putting on the brakes, the vacuum-chamber being re-exhausted through the plain pipe by an action subsequently to be described. (Reinforcing the vacuum is a term sometimes used, but it is so grossly illogical that I exclude it.)

Fig. 108 shows a vertical section of the ejector apparatus used with the Eames's brake. *f* is the end of a pipe opening from the boiler, whence, through the cock *t*, the steam passes to the small ejector *e*, which exhausts and keeps exhausted the automatic pipe and vacuum-vessel (*e*, Fig. 107), the steam and air passing away through the passage *r* into the waste-pipe *s*.

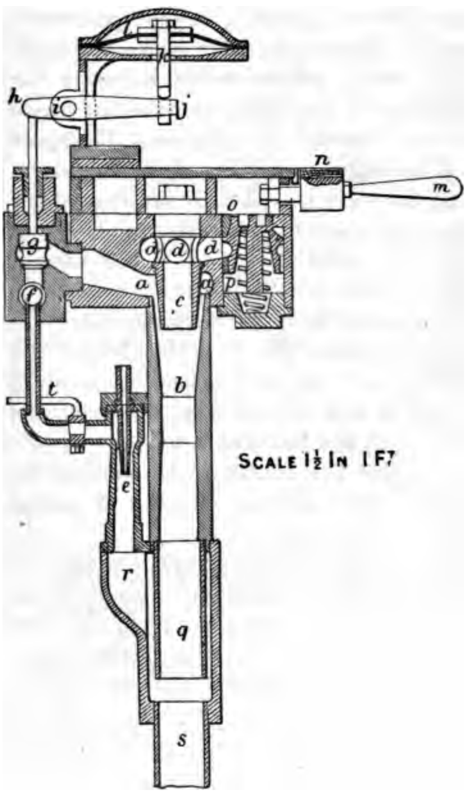


Fig. 108.

The automatic pipe is in communication with the space above the elastic diaphragm *l*, connected with the stem *k*, the lower end of which holds the end of the lever *j h*, carried on a centre *i*. Now so long as the vacuum is maintained above the diaphragm *l*, the valve *g* is held down over the steam opening *f*; but directly that vacuum is lost, the steam forces up the valve *g*, and rushing through

the passages *a a*, actuates the large ejector *c*, and acting through the valve (*m*, Fig. 107), re-exhausts the chamber (*a*, Fig. 107). From this it will be seen that as soon as the vacuum in the plain pipe exceeds that in the vacuum-chamber (*e*, Fig. 107), the valve (*m*, Fig. 107) will open, and (*l*, Fig. 107) close, the brakes being then held on through the plain pipe. It is evident, then, that the act of destroying the vacuum in the automatic pipe not only brings the vacuum vessels (*e*, Fig. 107) into action, but also starts the large ejector *c*.

q is the waste-pipe from *b*, the jacket of the large ejector *c*. To destroy the vacuum in the plain pipe and release the brakes, the engine-driver actuates a slide-valve worked by the handle *m*, secured in its position by a spring catch, *n*; then the atmospheric pressure forces down the valve *o*. and through the passage *d* the air enters the large ejector and plain pipe. *p* is a light spring to hold the valve *o* up to its seat when not in action. In case of an accident occurring, smashing both automatic and plain pipes, and leaving the brakes on, they can be released by hand, by opening the valve *n* by the lever *m*.

There is great difficulty in determining the relative efficiencies of brakes, because there have never yet been made any trials which afford information on the subject of any practical value.

The way in which trials have been made are as follows:—Several trains fitted with different brakes have been run on a certain length of railway, the distances run after application of brakes, and the corresponding times being registered with more or less (generally less) accuracy; then from such trials tables have been calculated and reports printed. The utter worthlessness of such tables and reports is so obvious that it is almost waste of space to point it out; but still as my younger readers might be misled in this matter, a little explanation may be allowable.

In the trials referred to the retarding effects of the train friction has not been taken into consideration, but the reductions to a common speed have been worked on the very false supposition that all the trains exhibited the same tractive resistance; hence the results *printed*, I can hardly say arrived at, are about as useful, practically, as the imaginings of the ancient alchemists. In order to compare fairly competing systems, they should be fitted to one and the same train of carriages, and being applied in succession under the same conditions, an estimate of their relative values may be made. This of course would involve considerable outlay, and as *some interest* leads to the outlay incurred in these trials, it is not likely that any reliable experiments will be made until the matter is taken up by the Government.

I shall now leave this generally unsatisfactory subject, and pass to the consideration of INTERLOCKING GEAR.

The interlocking gear to which I refer is that used to prevent, mechanically, the possibility of putting railway signals and points in such positions as may lead to accidents; and in the first place it is necessary to show what is required for safety. The methods of securing it are numerous, but mostly clumsy.

The normal position for a signal on a railway is at "danger," and from this position it is drawn (down or up as the case may be) when the line is clear for the passage of a particular train; moreover, the signals should be so arranged and weighted that if any signal-wire breaks, the signal with which it is connected will remain at danger; or, if not in that position, will fly to it.

Such mechanical arrangements must also be applied as will prevent the possibility of putting the signals in contradiction to the points, and *vice versâ;* and similar appliances should control the gates at "level crossings" —*that is,* where roads cross the railway on the same

level, and where, therefore, the traffic passing by road stops that by railway, and the reverse.

It is evident that very simple mechanical elements will be sufficient to secure what is required, when only a few levers working the points and signals are necessary; but at large stations and junctions the machinery becomes very extensive, and the more so as, in addition to the locks connecting the action of the signal with the point-levers, others are requisite to control the points in such a way that it shall be impossible to move them during the passage of a train over them. The multiplication of such simple appliances as rocking-levers working by wedge actions will cause an amount of friction almost too great to be overcome by manual force; hence some more easily worked machinery is necessary.

In Fig. 109, A shows a front view and B a vertical section of an arrangement of locking gear invented and patented by Mr. R. Elliott Cooper and myself some years since (the Patent-right was purchased by Messrs. Saxby and Farmer); the object being so to arrange the elements that the gear might work with a minimum of friction, and by simplicity of parts to secure economy, both in first cost and subsequent repairs and renewals. The principle of the apparatus is as follows:—Attached to each lever and revolving upon the same axis with it is a very slow-threaded screw, which, taking into a notch in a bar placed parallel to the axis upon which the lever oscillates, moves such bar longitudinally in one direction or the other, according to whether the lever is pulled over or pushed back. Not only is the sliding-bar so moved, but by reason of the thread of the screw holding in the notch, the bar is retained in the position to which it has been moved until the signal or switch lever is restored to its former position, when a notch in the screw-thread is brought opposite the sliding-bar, so that the latter is free

to be moved by another thread; and when so moved the sliding-bar, by taking into the notch of the first screw, will hold, or *lock*, it and its lever until another movement is made.

In the figure the same letters refer to the same parts in both views. At B, the vertical section, is seen *a*, the lever, fixed in the boss *b*, carrying the screw thread *d*, in which are two notches *g g*, one for front and the other for back locking; *c c* are two sliding bars (of which any required

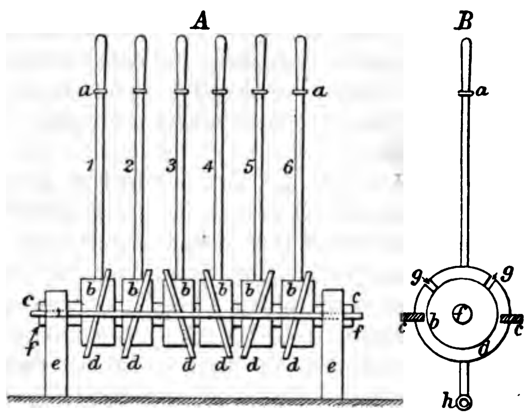


Fig. 109.

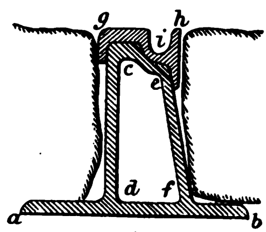
number may be placed around the boss *b*); the boss and lever oscillate upon the dead centre *f*; *h* is the lower end of the lever to which the switch rod is attached (in the case of a signal lever, locking in one direction only is requisite).

In A, the front view, are shown six levers, *a* 1 to *a* 6, with their bosses *b* and screw threads *d* carried upon a common dead centre *f f*, supported in frames *e e*; *c c* is the front sliding or locking bar.

By pulling over lever *a* 1, *c c* will evidently be travelled

to the right, and thus will lock certain other levers; then by pulling over lever *a* 2, the same bar, travelling farther, will lock *a* 1, so that *a* 1 cannot be put back unless *a* 2 has previously been put back, when, reciprocally, the motion to the left given to the bar *c c* by the screw of *a* 1 will lock *a* 2. I think this will be sufficient to illustrate the principle of action of the apparatus, and therefore will not occupy more space with its description; its simplicity is obvious.

Of late years great advances have been made in the matter of road tramways, and efforts to establish steam traction upon them have been persistent. The difficulties presenting themselves, so far as the use of the steam-engine is concerned, are identical with those that obstructed the introduction of the common traction-engine, viz. noise, &c. tending to frighten horses; but in addition to this, there has been some trouble in finding a rail that shall suit alike the users of the tram and those of the road. In Fig. 110 is shown a section of tram-rail recently laid in Leeds by Mr. T. G. Hardie, the patentee; it appears to me to possess several points of great value. The chair, which is continuous, is shown by the section *a d c e f b*, and upon this (which is of cast iron) is placed the wrought-iron rail *g i h*. The web *c d* is of greater thickness than that *e f*, for the former is under the centre of gravity of the load. In the rail itself the groove *i* is made much deeper than in the ordinary tram-rails, and on the left, that is, the "tread" side of the wheel, its side is *vertical*, so there can be no friction against it of the flange. The general arrangement will be seen, from the figure, to be such that the paving can be laid close up to the wrought-iron rail.



Scale 1½ in. 1 Foot.

Fig. 110.

CHAPTER XIV.

MILL-WORK, GEARING, AND MACHINERY.

THE steam-engine in a mill is the prime mover of a train of machinery driven by SHAFTS, BELTS, TOOTHED GEARING, and various other appliances. Such mechanical appliances I am now going to describe.

I will first deal with that case in which the power of the steam-engine is transmitted in the first instance by a belt. Now it is evident that the strain upon the belt, taken at its maximum, will be equal to the total pressure on the piston multiplied by the radius of the crank and divided by the radius of the driving-drum, pulley, or rigger; thus, for instance, if we have a piston of which the area is 530 square inches, with a maximum initial pressure of 50 lbs. per square inch, we shall have a total force upon that piston of 26,500 lbs., and assuming the crank to be 24 inches radius, and the driving-drum 36 inches radius, the tension upon the belt will be 39,750 lbs., and the belt must be proportioned to bear this strain and a margin allowed for the jerks consequent upon starting the engine, and also those accruing from sudden alterations in load or resistance, such, for instance, as the sudden throwing into gear of circular saws.

In making RIGGERS to carry belts it is necessary to bear in mind that their peripheries should not be portions of cylinders, but should have the figure of the greatest zone of a sphere, otherwise the belts will be liable to slip off: *the reason* of this is easily explained; if one part of the

periphery of a rigger is of greater diameter than another, the belt will be more strained at that part than at those where the diameter is less, hence the band will always exhibit a tendency to rise to the highest part of the periphery of the rigger or drum upon which it is working; hence if the periphery is spherical in its form, the belt will always tend to keep upon its centre.

It is necessary that riggers should be accurately turned, so as to revolve truly about their centres of suspension, for if there be any eccentricity in their revolution it will cause the belts to slip, losing their hold as the shortest radius comes into action: and it is moreover important that the peripheries should be smooth, as any rugosity may cause the belt to slip. It will also be necessary to proportion the width of the rigger to its diameter, so that the friction between the belt and the surface of the rigger is sufficient to transmit the maximum power required by the machine driven by such rigger.

The coefficient of friction of strap or belt leather upon cast iron is ·38 of the radial pressure; hence calling the tension 40,000 lbs. we shall require for such a belt a radial pressure of $\frac{40000}{\cdot 38} = 105263$ lbs., and the rigger must be made strong enough to bear this strain. If the rigger is made with arms, each arm must be strong enough to carry safely as working load the whole radial pressure, which is about 47 tons. The ultimate strength of cast iron is 45 tons per sectional square inch, and we may assume that the arms of the riggers are sufficiently short to exert the whole resistance of the metal without flexure; hence taking 10 as the factor of safety, the working strength will be 4·5 tons per sectional square inch, we shall therefore require in each arm of the rigger 10·4 square inches.

This radial strain will also come upon the shaft in the form of shearing strain tending to shear through the shaft

at its points of support. I shall here assume that the shaft bearings are placed as any *competent millwright* would place them, that is, close to the rigger, then we shall have no bending strain upon the shafting; the ultimate shearing strength of wrought-iron bars may be taken as 22 tons per sectional square inch, then the working resistance will be 2·2 tons per sectional square inch, and for the above strain the area of journal required will be $\frac{47}{2 \cdot 2} = 21 \cdot 3$ square inches, corresponding to a minimum diameter of (say) $5\frac{1}{4}$ inches, and in no part of the main driving shaft must the diameter be less than this.

Where the shaft bearings are carried by brackets, or hangers, care must be taken to provide in such brackets, or hangers, sufficient strength to resist the transverse strain brought upon them regarded as cantilevers.

For the method of determining the strength of such cantilevers, I refer my readers to my treatise "Materials and Construction," in which transverse strains are dealt with.

It is necessary that the shafting should be accurately turned, otherwise a sag will occur, which, by the revolution of the shafting, will gradually BELL-MOUTH the bearings in which such shafting revolves.

Where the machinery to be driven requires a power greater than that which can conveniently be transmitted by belts, TOOTHED WHEELS, or SPUR-GEARING, must be employed, or in some cases the TANGENT SCREW and WORM-WHEEL will be preferable. As in all kinds of machinery screws are required either to hold the framework together, or as an element in the running gear, I will now describe the use of the lathe as used for cutting screws.

A, Plate II., shows a lathe in which the leading screw passes longitudinally through the bed of the machine; by *this screw* the slide of the lathe is travelled longitudinally.

Now let us suppose that we wish to cut a screw with a thread the same as that of the leading screw of the lathe: if we put such spur-wheels upon the end of the leading screw and the headstock of the lathe, that the work being operated on in the lathe revolves once for one revolution of the leading screw, the thread cut upon such work will be of the same PITCH as the leading screw itself. By pitch is meant the distance from the centre of the thread measured to the centre of the same thread after one revolution, such measurement being of course measured parallel to the axis of the screw. A screw is not necessarily single threaded; that is to say, several threads may be cut upon one axis, and where quick-threaded screws are required, multiple threads are commonly used, in order to give the strength requisite without inordinately enlarging the diameter of the screw.

While speaking of strength I may as well point out that the strain upon a screw tends to shear off the thread; ordinary iron, bearing 22 tons per sectional square inch, will give a working strain of 2·2 tons per sectional square inch. In a square-threaded screw, accurately cut, the whole shearing surface is available; but for common iron a wider margin should be allowed.

There is no manufactured article known to mechanical engineers in which the workmanship varies so widely as in screws and bolts. In engine-work the screws are usually made of tough scrap-iron, and are accurately turned, or CHASED, in a lathe. Good threads may be obtained in screwing-machines by the use of dies properly formed, because the manufacturers of engines and machinery generally take a pride in turning out creditable work; but, on the other hand, the bolts supplied by bridge manufacturers are commonly "scamped" up in a screwing machine driven at a higher velocity than the metal used is fitted to sustain, the result being a thread partly cut and

partly squeezed up, which, instead of presenting a clearly-defined edge on its summit, exhibits only too often a *ragged* groove; and the unscrewed part of the bolt, instead of being properly turned (even if specified so to be), is brightened up on a "Sheffield file"—that is, a grindstone.

To return to the method of cutting screws correctly. If we require a screw differing in pitch from the leading screw of the lathe, it will be necessary to interpose such CHANGE WHEELS as are required to time the revolutions of the work in the lathe to those of the leading screw; thus, if the leading screw have a pitch of 1¼ inches, and we want a screw of 1 inch pitch, the radii of the wheels connecting the mandril with the leading screw must be as 4 to 5. Screw-cutting lathes are furnished with change wheels requisite to produce all pitches ordinarily required. If a left-handed screw is required, this is obtained by reversing the motion of the slide-rest, by the interposition of an IDLE WHEEL, which reverses the motion of the leading screw without altering the pitch of the thread.

In order to secure good and clean work, the cutting edge of the tool should be so turned as to cut at an angle corresponding to the pitch of the thread; and in some cases it will be necessary to lay the cutting tool on its side, this being required in the case of very quick-threaded screws—such as occurred in some steering gear constructed by Messrs. Westwood and Baillie in 1866, which I will now describe as affording the best example which has come within my personal experience.

In the apparatus to which I refer there was, attached to the top of the rudder-post, a cast-iron cylinder in which a very "slow thread" was cut completely through the thickness of the cylinder; into this thread fitted slides actuated vertically—that is, in the axis of the cylinder—by an *ordinary slow*-threaded screw; these slides were prolonged,

and at their outer ends worked in vertical guides. The pitch of the thread was about 3 feet on a diameter of 10 inches. The screw-cutting lathes are not furnished with change wheels suited to give so quick a pitch: hence it was necessary to cut a new leading screw of the quickest thread the machine could produce, and by means of that to actuate the slide-rest, laying the cutting tool upon its side so that it cut at an angle of about 10° to the horizon.

While dealing with screws I may as well describe the TANGENT-SCREW and WORM-WHEEL, an elevation of which is shown at Fig. 111. Here the screw, instead of working in a nut, actuates the teeth of a properly cut wheel. *a a* is the shaft upon which the tangent-screw *b* is cut, this screw taking into teeth upon the periphery *e* of the wheel *d*, carried upon the shaft shown in section at *f*. As the power transmitted to the wheel causes a longitudinal strain upon the shaft *a a*, it is necessary to provide some resistance beyond that ordinarily afforded by shaft-bearings; this is done by turning grooves *c c* in the shaft, the bearings having collars to fit them.

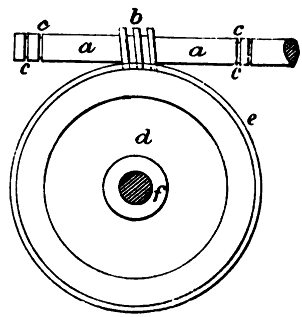


Fig. 111.

In making these worm-wheels it is highly important that the teeth should accurately fit the tangent-screw; therefore, after the wheel has been roughly cut, the teeth should be finished by a HOB of the same diameter as the tangent-screw intended to work in the worm-wheel. A hob is a steel screw with its thread cut at intervals so as to form cutting-edges, which cutting-edges clean out the teeth of the worm-wheel so that it will accurately fit the

tangent-screw; and the importance of this is great, as the only objection to this powerful mechanical combination is the friction between the screw-thread and the teeth of the wheel. Its great advantage over spur gearing is, that whereas in the latter we have to rely upon one tooth of a wheel, in the former the thread has hold of three or four or more teeth of the worm-wheel. In case of excessive friction, it may be as well to put a little flour-of-sulphur into the oil used for lubricating the tangent-screw, and also the bearings in which its shaft revolves, as such a precaution prevents heating. It is, however, only fair to say that with properly designed SPUR GEARING there is no friction whatever between the teeth.

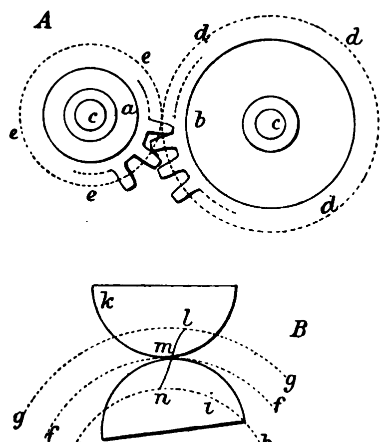


Fig. 112.

In spur gearing the teeth must be made of such a form that their contact produces only rolling motion. In order to obtain this result it is necessary that where the teeth of the wheels meet, a tangent plane to the lines of contact should be at right angles to the direction of the force transmitted from one wheel to another. The cycloidal form of tooth meets the conditions thus imposed, and the method of drawing the profile of such tooth is shown in Fig. 112. A is an outline elevation of a pair of spur-wheels, on each of which are shown three teeth; of course *these teeth* in practice are continued all round the wheels.

c c are the shafts carrying the spur-wheels, *a* and *b*; the virtual circles of contact, called the PITCH CIRCLES, are indicated by the dotted circles *d d d* and *e e e*. At B, *f f* is the pitch circle, *g g* the outside circumference of the wheel, and *h h* a circle struck at the roots of the teeth, *k l* and *n i* are segmental templates. A pencil being attached to *k l* at the point *m* will, when the segment *k l* is caused to roll upon the pitch circle *f f*, describe a line *m l*; and in like manner a pencil attached at the point *m* to the template *n i* will, when *n i* is caused to roll on the inside of the pitch circle *f f*, describe the line *m n*; then *n m l* will be the profile of the tooth. The part *m l* is an epicycloid, and the part *m n* is a hypocycloid. If we have a tooth-wheel gearing in a rack, the template for the rack will roll upon a straight line.

We have now to consider the strength of the tooth. A cantilever of sound cast iron, 1 inch long and 1 inch square, will break with a load of 8,000 lbs. applied at its end; therefore, using the same factor as before, the working load will be 800 lbs. Now the strength of the teeth will vary inversely as their length, directly as their breadth, and as the squares of their thickness (*see* "Materials and Construction," by the author).

The following are the proportions practically adopted for the teeth of wheels.

Pitch	100
Depth	75
Working depth	70
Clearance	5
Thickness	45
Width of space	55
Play	10
Length beyond pitch-line	35

The proper thickness of tooth, the length being 2 inches, will be $\frac{2 \times 45}{70} = 1 \cdot 29$ inches, hence the working strength

of the teeth per inch of breadth will be $\frac{800 \times (1 \cdot 29)^2}{2} =$ 664 lbs., and the breadth of the wheel must be determined accordingly.

I will now point out the means of proportioning wheels of all descriptions in such a way as to avoid their breaking by the centrifugal energy of their rims.

From the ordinary principles of mechanics it follows that any wheel may be driven at such a velocity that the centrifugal force will overcome the tensile resistance of the metal, in which case the wheel will fly to pieces.

For cast-iron wheels, let $n =$ number of revolutions per minute which must not be exceeded, or the limiting velocity; $d =$ diameter of wheel in feet; $f =$ factor of safety $(= 10)$; then—

$$n = \frac{8000}{d\sqrt{f}} = \frac{2530}{d}.$$

As well as the shearing strain mentioned above, there will be upon the shafting a twisting or torsional stress, and the diameter at the smallest part must be proportioned to carry safely such torsional strain as may be brought to bear upon it.

Let H P be the maximum horse-power to be transmitted by the shaft; N the number of revolutions per minute of the shaft; and d the least diameter of the shaft in inches; then,—

$$d = \sqrt[3]{\frac{320 \times \text{H P}}{\text{N}}}.$$

It is frequently necessary to be able readily to stop or reverse the motion of a particular shaft, without interfering with the rest of the running machinery; for this purpose *a* CLUTCH *is* used; a very useful form of this detail is illustrated *in Fig.* 113. A is a general view in which b is the

driving shaft, carrying at its end a BEVELLED SPUR WHEEL *d*, which gears into two other bevelled spur wheels *c* and *e*, placed on the *driven* shaft *a a*. The wheel *d* is firmly fixed and keyed on the shaft *b*, so that it must revolve with that shaft. The wheels *c* and *e* are so placed upon the shaft *a a* that they can revolve upon it without turning it, not being keyed on, but only retained by collars which prevent these wheels from shifting *longitudinally* upon the shaft.

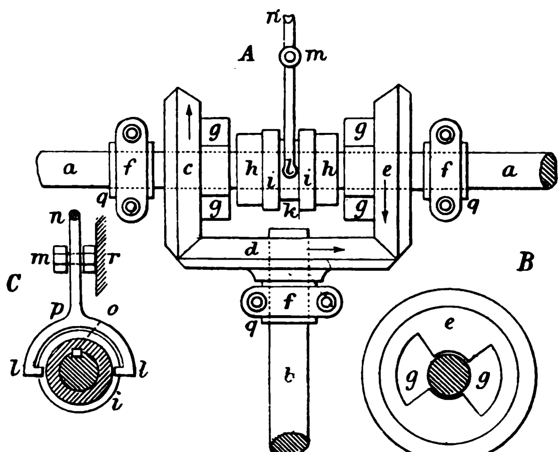


Fig. 113.

If the wheel *d* revolves to the right, as shown by the arrow, then the wheels *c* and *e* will revolve in the directions respectively shown by the arrows upon them—therefore in contrary directions. Each of the wheels *c* and *e* is formed with projections *g g* upon the face, these projections being shown in front elevation at B. The shafts *a a* and *b* are carried in bearings *q q q* fitted in plummer blocks *f f f*. Upon the shaft *a a* is fitted a clutch *i i*, in such a manner that it *revolves* with the shaft, but admits of being moved

longitudinally upon it; this longitudinal movement is imparted by the forked lever *n m l*, shown broken off at *n*, in which direction it is prolonged, terminating in a handle; at *m* is a pin or DEAD CENTRE upon which the lever moves; at *l* are projections taking into a groove *k* in the clutch, so that while the latter can *revolve* freely its longitudinal motion is controlled by the lever *n m l*. This lever is shown in another view at C, the same letters being used, with the addition of *p*, showing where the lever joins the fork *l p l*; *r* a part of the framework to which the dead centre *m* is fixed, and *o* a kind of key called a FEATHER, which being *firmly fixed* in the shaft *a a*, causes it to revolve with the clutch *i*, although the groove in the latter is sufficiently easy upon the feather to allow of its sliding horizontally upon it. *m* is termed a "dead" centre, because although it is a centre of motion, it does not itself revolve. The clutch *i i* is fitted with projections *h h*, corresponding to the spaces between the projections *g g* on the wheels *c* and *e*: if, therefore, when the wheels are revolving, this clutch is pressed towards one of them, it will gear with that one, and the shaft *a a* will revolve in the same direction as the wheel with which the clutch has geared, until the clutch is again restored to the position shown in the figure; and so long as it remains in this position the shaft *a a* will be at rest, the wheels *c* and *e* revolving freely upon it.

In cases where irregular or intermittent motions are required, CAMS of various forms are frequently used: one form has already been illustrated, used for actuating the expansion valves of certain kinds of marine engines. I will now describe a few more types of cams commonly used.

Fig. 114 is a front elevation of a FACE CAM, having in its face a groove *c c c*, the form of which is varied according to the kind of movement required. *a* is the end of the shaft carrying this cam, *b* the cam plate, and *e e* a rod

capable of sliding vertically in the guides *d d*. At the lower end of the rod *e e* is a pin *f*, around which is a roller to reduce friction; this roller resting in the groove *c c c* as the cam revolves, the rod *e e* is raised and lowered, both its inward and outward movements being controlled by the cam which *has hold* of the roller on the pin *f*.

In Fig. 115, A is a front elevation and B a plan of a

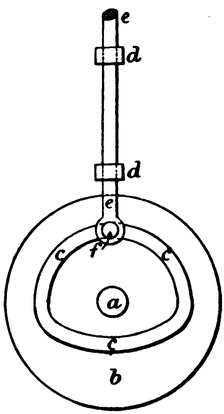


Fig. 114.

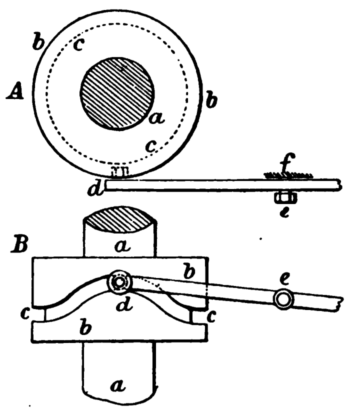


Fig. 115.

CAM GROOVED ON ITS EDGE. *a, a a* is the shaft carrying the cam *b b*; the undulating groove *c c*, shown in elevation by the dotted circle, holds a roller on the pin *d* attached to the end of a lever oscillating as the cam revolves upon the dead centre *e*, fixed to the framing of the machine at *f*.

Fig. 116 is a FACE CAM, A being a front elevation and B a plan. In this arrangement the roller at the end *d* of a lever *e*, carried upon a dead centre *f*, attached to the framing at *g*, is (by a spring or weight) held against the face of the cam *b*, carried on a shaft *a, a a*; as the cam revolves the roller *d* will be forced forward by the raised

part *c*, returning after that part has passed to its normal position; the motion is in the direction of the arrow.

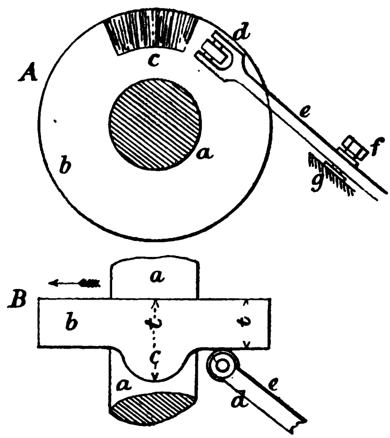


Fig. 116.

Assuming the back of the cam as a plane at right angles to the axis of revolution, the amount of "travel" given to the roller will be $t'-t$.

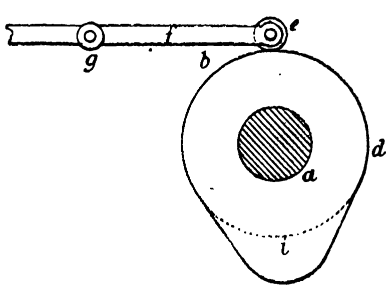


Fig. 117.

Fig. 117 shows a form of EDGE-CAM, *b d*, carried on a shaft *a*; against its edge is pressed the roller *e*, carried by the lever *f* rocking on a dead centre *g*. As the raised part *c* of the cam passes the roller *e*, the latter is lifted and returns as *c* passes from under it; the roller *e* is placed behind the

bar *f* at a sufficient distance for the latter to be cleared by the cam; *i c* is the travel of the roller.

In Fig. 118 is shown an elevation of a kind of cam called from its form a SNAIL. In this arrangement the lifting of the lever is gradual, but its fall, or return, instantaneous. *a* is the shaft, *d c b* the periphery of the snail, *e* an arrow showing the direction of motion, *f* the roller, *g* the rocking lever, and *h* the dead centre upon which the lever oscillates. The travel of the roller is *d b*. The snail, however, instead of having an unbroken periphery from *d* through *c* to *b*, may be made in a series of steps, as in the familiar case of the snail of the striking train of a clock, which regulates the number of strokes made by the hammer. It is evident that if this arrangement be turned the wrong way, something must be damaged or displaced, if it be moved far enough for the roller *f* to come in contact with the edge *d b*; hence the danger of putting back the hands of a striking clock.

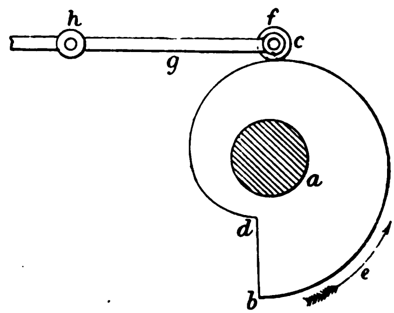


Fig. 118.

It is obvious that the forms in which cams may be made are in number infinite, and every possible gradation of movement may, by means of them, be obtained; but having shown some of their generic forms, it would be superfluous to occupy further space in describing and illustrating these interesting elements of machinery.

We must now consider the effects of machines, in varying velocities and static pressures; the pressures at the opposite ends of a machine will of course be in the inverse

ratio of the velocities with which those parts travel, but with a certain loss in the delivery of power arising from the friction of the various parts of the machine; this, however, for the present is neglected. I will take, for example, a crane which is required to lift 30 tons; the average force that a man can exert, on a winch handle of 16 inches radius, is 30 lbs., hence the average dead pull of four men upon such a winch will be 120 lbs.; now 30 tons is equal to 67200 lbs., and $\frac{67200}{120} = 560$; hence the pressure applied by the men actuating the winch must be multiplied 560 times, and this must be done by proportioning the gearing of the crane so that the load lifted moves 560 times slower than the winch handle to which the moving power is applied.

The relative velocities will be as the radii of the wheels used in the winch gearing; thus, if on the winch handle we have a pinion 8 inches in diameter, on the pitch circle we shall have a radius of 4 inches against 16 inches radius of winch handle, thus multiplying the pressure applied by 4: let this pinion work with a wheel on the second shaft 30 inches in diameter, and upon the same shaft let there be a pinion 6 inches in diameter on the pitch circle; this will multiply the pressure transmitted to the wheel by 5, and the pressure applied to the winch by $5 \times 4 = 20$. If the pinion on the second shaft gear with a wheel 24 inches in diameter, carrying upon its shaft a pinion 6 inches in diameter, gearing with a wheel 35 inches in diameter fixed upon a shaft, upon which is keyed a barrel 5 inches in diameter, the necessary power will be found exclusive of friction. For friction we should allow in well-made cranes 10 per cent.

There is another matter to be considered in connection with such machines, which is their foundations, which must have sufficient weight to prevent their being overturned.

CHAPTER XV.

MATERIALS.

In concluding this treatise I think it necessary to make a few remarks upon the materials used in the construction of steam-engines, boilers, and machinery; for the use of defective material may lead to such appalling catastrophes, that it is impossible to take too much precaution to prevent failure. One boiler explosion may cause the loss of many valuable lives, and inflict on many others that which is worse than loss of life, an incapacity to pursue those avocations which up to that time have brought them the means of supporting themselves and their families.

For all the working parts of steam-engines, thoroughly sound "scrap iron" should be used. The castings should be made of tough grey cast iron, showing when broken a granular fracture. The boilers should be of sound Staffordshire iron, or for first-class work of Bowling or Low Moor plates. I should not recommend STEEL in any case to be used for boilers; the material itself requires such close watching both in its manufacture and in its working, that unless the makers are prepared to provide a staff of competent engineers to watch each plate from the bloom to its riveting up in the boiler, it cannot be relied upon.

Generally there is little fault to be found with the makers of engines and boilers, so much depends upon their own skill, and so thoroughly are they relied upon for the perfection of their work, that inspection becomes unnecessary.

The young engineer may, however, and indeed in colonial practice often will, find himself in a position where he cannot command the services, or even the advice and assistance of experienced practical mechanical engineers, in which case it is obvious that he must fall back upon his own knowledge of materials.

Although we say "generally" that cast iron should be tough and exhibit when broken a granular *dull* grey fracture, this is not a sufficient test upon which to rely solely. The force required to break the metal must be considered, for there may be many bars apparently the same which will exhibit considerable differences in resistance.

Cast iron, up to a certain point, becomes better at each re-melting, and mixtures of different kinds of iron will very commonly give better results than could be obtained by using separately any of the irons in a particular mixture.

It would obviously be useless here to specify any particular mixtures, as, under the circumstances we are considering, the engineer must work with whatever irons may be obtainable in the district in which he happens to be located. Hence he must experiment until he finds a quality sufficiently strong for his purpose.

Repeated blows and vibrations constantly tend to cause a crystalline disposition in metals; therefore, in the first instance, it is desirable to obtain our materials as nearly fibrous as possible: though, of course, cast iron cannot be fibrous, yet a granular structure will insure a certain amount of flexibility which is essential to all parts of machines, in order that they may resist without fracture the concussions inevitable in their working.

The cast iron should be tested in tension, and under transverse strain. Its compressive resistance may always be taken as not less than five times its tensile resistance.

Cast iron should not be used of a less strength in tension than 8 tons per sectional square inch, and this may be taken as a good quality, although cast irons *have* been produced more than half as strong again (for purposes of gunnery), but at an outlay which would not be justified for work of the class with which we are now dealing.

The test-bars for tensile strength should at one part have the sand-skin cut away, and be there trued to fixed dimensions, and at that (smallest) section the bar if uniform will break. The bars for transverse testing (from which the sand-skin should be thoroughly rubbed) should be 3 feet 6 inches long, 1 inch wide, and 2 inches deep, and be placed on edge on supports 3 feet apart; such a bar when loaded in the centre should not break with less than 30 cwt., and it should deflect regularly for each increment of load up to breaking point, and not snap suddenly.

In respect to wrought-iron, the colonial engineer will not have to do with mixing irons nor except in very exceptional cases in making scrap-iron up, but will work direct the iron supplied from civilized centres.

First-class boiler-plates will carry 30 tons per sectional square inch before breaking, and the best Staffordshire girder-iron will carry 25 tons in tension, and 16 in compression. The north country iron does not show such good results, 22 tons tension being considered a very high figure; and although 21 tons is often specified, we doubt if it is often got, and frequently it is down to 19 or even 18 tons per sectional square inch.

Wrought iron when broken should show a well-defined "thready" structure, the fibres stretching well before breaking, and any iron of which the test-bars show the slightest signs of bright or crystalline structure is to be immediately rejected for any kind of machine or boiler work.

In transverse strain, for equal qualities of raw materials, solid wrought-iron bars should bear half as much again as cast iron of the same dimensions.

As in the earlier part of this work we have shown how to manufacture the material used by the mechanical engineer, so in conclusion are given the tests they should bear when manufactured.

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